April 2001

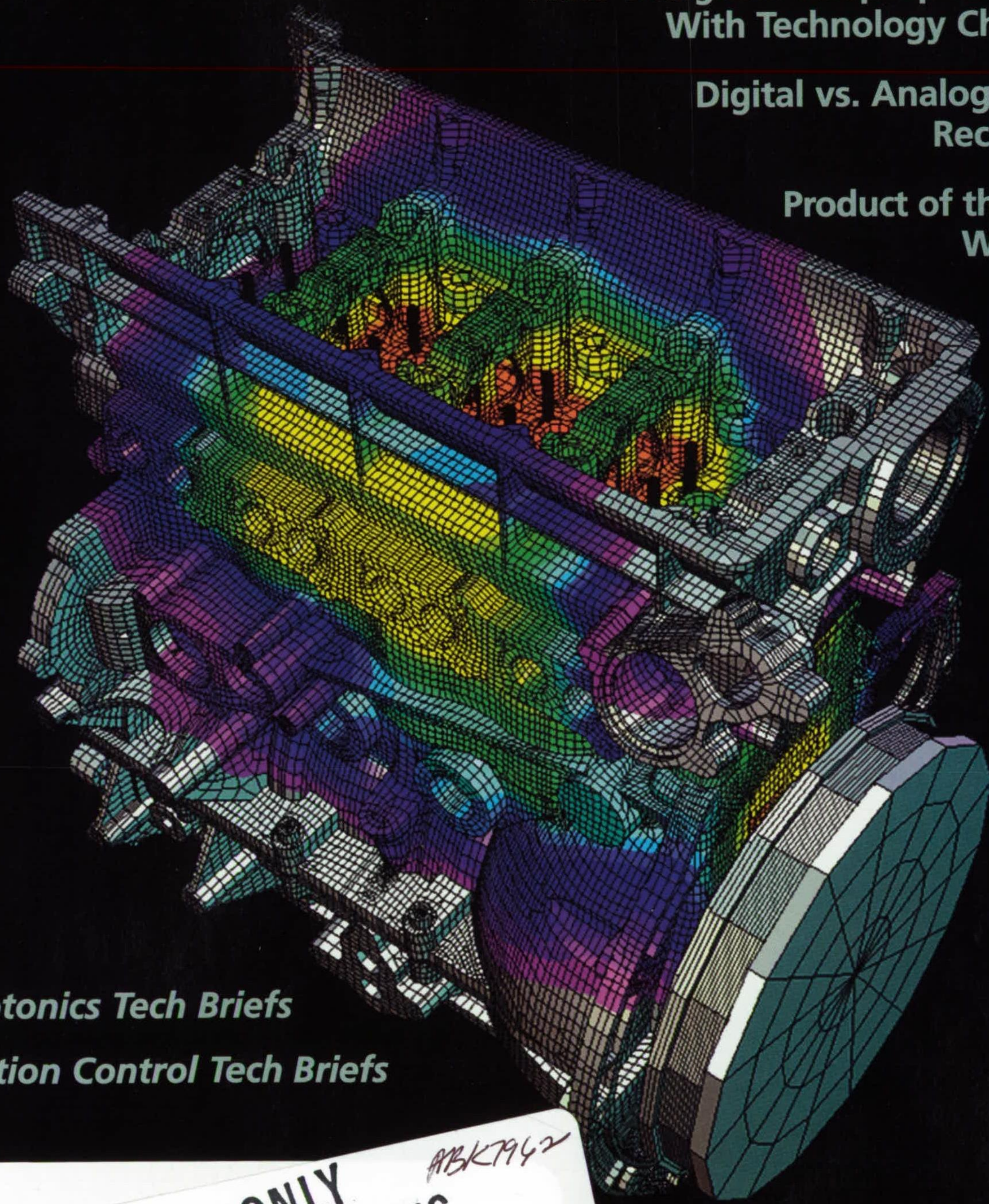
TECH BRIEFS

ENGINEERING SOLUTIONS FOR DESIGN & MANUFACTURING

Auto Designers Keep Up to Speed With Technology Changes

Digital vs. Analog Video Recording

Product of the Year Winners



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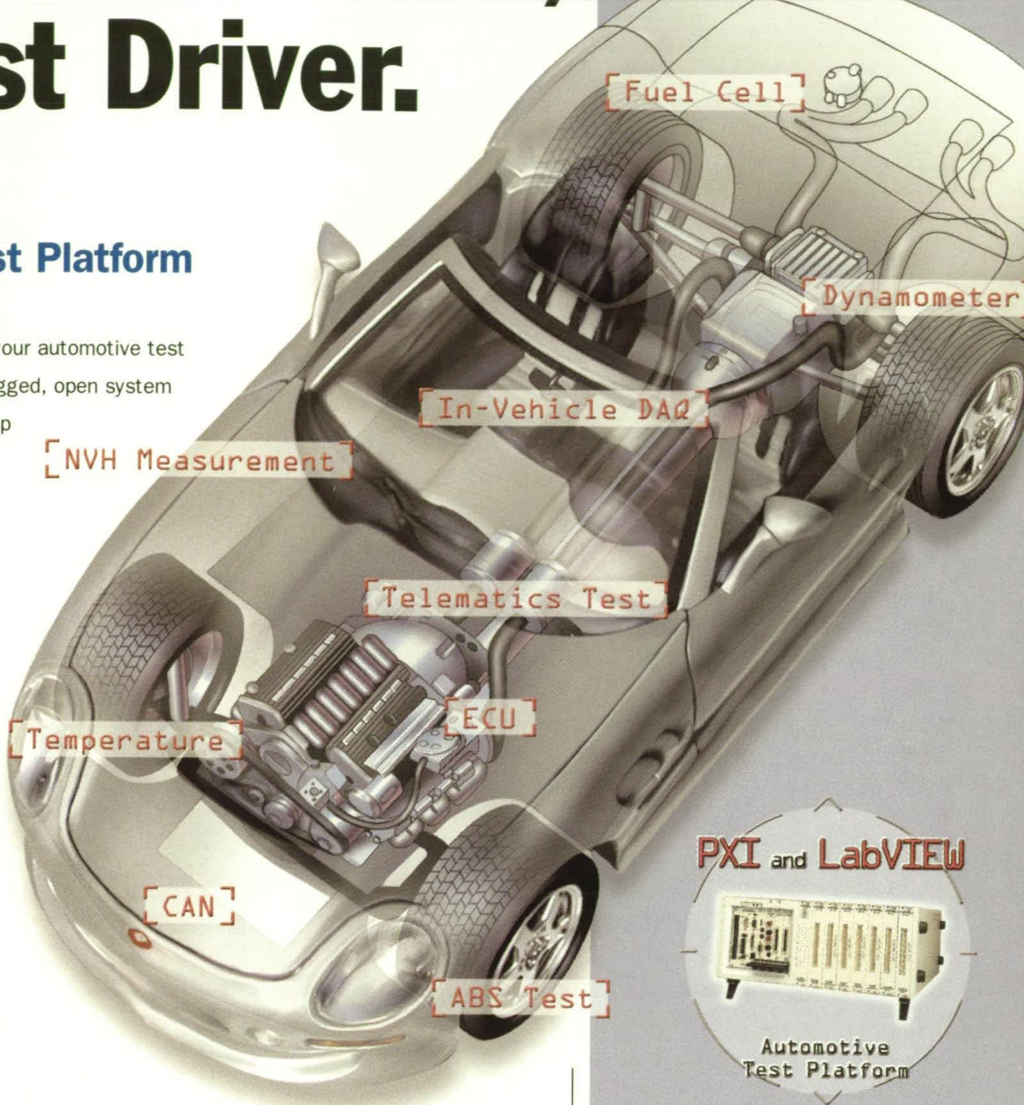

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NASA TECH BRIEFS
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Motion Control Tech Briefs

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Motion Control Tech Briefs

Follows page 64 in selected editions only.

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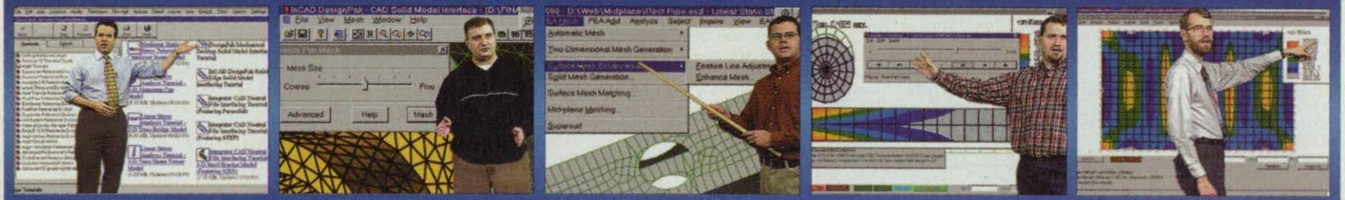

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PRODUCT OF THE MONTH

The OJ miniature photoelectric sensors from ifm efector, Exton, PA, are available with either a visible light or a laser light source.

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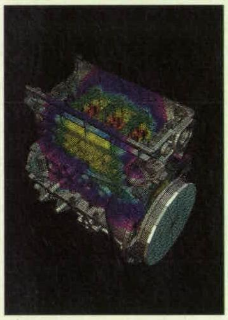
ON THE COVER



This complete engine was modeled with MSC.Marc finite element software for engineering simulation from MSC.Software, Costa Mesa, CA. The model takes advantage of automatic domain decomposition and parallel processing to analyze a system with millions of degrees of freedom. This type of simulation software is just one of the tools auto designers are using to keep up with technology innovations that will become standard equipment in tomorrow's cars. See the feature article on page 18 to learn about how auto designers stay up to speed.

(Image courtesy of MSC.Software)

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Published by .... Associated Business Publications
Publisher .... Joseph T. Pramberger
Editor/Associate Publisher .... Linda L. Bell
Associate Publisher, *Photonics Tech Briefs* .... Linda Silver
Editor, Market Focus Editions .... Robert Clark
Senior Editor/Internet Editor .... Jason C. Flynn
Production Manager .... Margery Koen
Assistant Production Manager .... John Iwanciw
Art Director .... Lois Erlacher
Production Artist .... Christopher Coleman
Circulation Manager .... Hugh J. Dowling

BRIEFS & SUPPORTING LITERATURE: Written and produced for NASA by **Advanced Testing Technologies, Inc.,** Hauppauge, NY 11788

Technical/Managing Editor .... Ted Selinsky
Sr. Technical Analyst .... Dr. Larry Grunberger
Art Manager .... Eric Starstrom
Staff Writers/Editors .... Dr. Theron Cole, George Watson
Graphics .... Robert Simons
Editorial & Production .... Joan Schmiemann, Becky D. Bentley

NASA:

NASA Tech Briefs are provided by the National Aeronautics and Space Administration, Technology Transfer Division, Washington, DC:

Administrator .... Daniel S. Goldin
Director, Commercial Technology .... Dr. Robert Norwood
Publications Director .... Carl Ray

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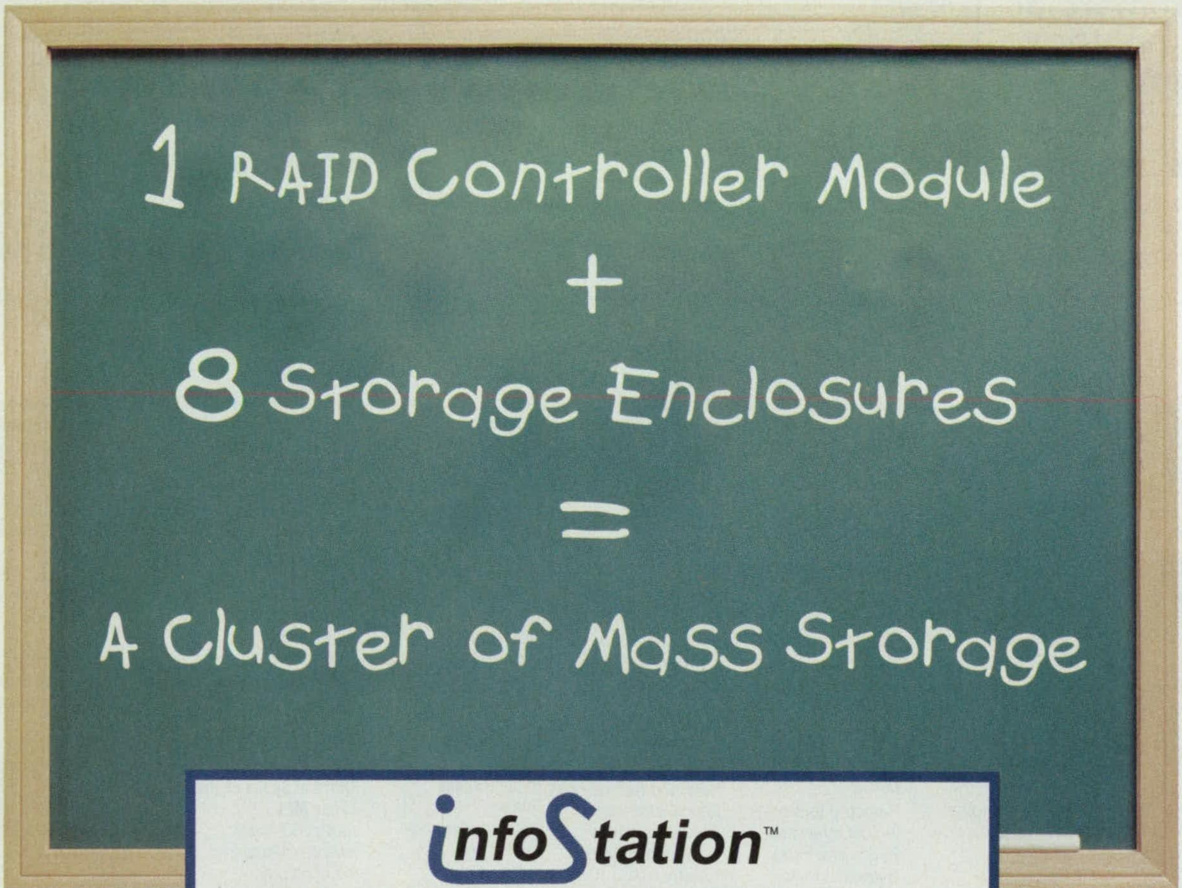

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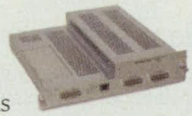

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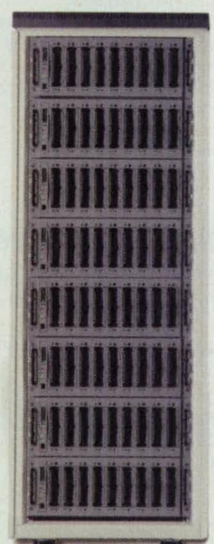

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NASA Commercial Technology Team

NASA's R&D efforts produce a robust supply of promising technologies with applications in many industries. A key mechanism in identifying commercial applications for this technology is NASA's national network of commercial technology organizations. The network includes ten NASA field centers, six Regional Technology Transfer Centers (RTTCs), the National Technology Transfer Center (NTTC), business support organizations, and a full tie-in with the Federal Laboratory Consortium (FLC) for Technology Transfer. Call (609) 667-7737 for the FLC coordinator in your area.

NASA's Technology Sources

If you need further information about new technologies presented in *NASA Tech Briefs*, request the Technical Support Package (TSP) indicated at the end of the brief. If a TSP is not available, the Commercial Technology Office at the NASA field center that sponsored the research can provide you with additional information and, if applicable, refer you to the innovator(s). These centers are the source of all NASA-developed technology.

Ames Research Center
Selected technological strengths: Information Technology; Biotechnology; Nanotechnology; Aerospace Operations Systems; Rotorcraft; Thermal Protection Systems.
Carolina Blake
(650) 604-1754
cblake@mail.arc.nasa.gov

Dryden Flight Research Center
Selected technological strengths: Aerodynamics; Aeronautics Flight Testing; Aeropropulsion; Flight Systems; Thermal Testing; Integrated Systems Test and Validation.
Jenny Baer-Riedhart
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jenny.baer-riedhart@dfrc.nasa.gov

Goddard Space Flight Center
Selected technological strengths: Earth and Planetary Science Missions; LIDAR; Cryogenic Systems; Tracking; Telemetry; Remote Sensing; Command.
George Alcorn
(301) 286-5810
galcorn@gsfc.nasa.gov

Jet Propulsion Laboratory
Selected technological strengths: Near/Deep-Space Mission Engineering; Microspacecraft; Space Communications; Information Systems; Remote Sensing; Robotics.
Merle McKenzie
(818) 354-2577
merle.mckenzie@jpl.nasa.gov

Johnson Space Center
Selected technological strengths: Artificial Intelligence and Human Computer Interface; Life Sciences; Human Space Flight Operations; Avionics; Sensors; Communications.
Charlene E. Gilbert
(281) 483-0474
charlene.e.gilbert1@jsc.nasa.gov

Kennedy Space Center
Selected technological strengths: Fluids and Fluid Systems; Materials Evaluation; Process Engineering; Command, Control and Monitor Systems; Range Systems; Environmental Engineering and Management.
Jim Aliberti
(321) 867-6224
Jim.Aliberti-1@ksc.nasa.gov

Langley Research Center
Selected technological strengths: Aerodynamics; Flight Systems; Materials; Structures; Sensors; Measurements; Information Sciences.
Sam Morello
(757) 864-6005
s.a.morello@larc.nasa.gov

John H. Glenn Research Center at Lewis Field
Selected technological strengths: Aeropropulsion; Communications; Energy Technology; High Temperature Materials Research.
Larry Viterna
(216) 433-3484
cto@grc.nasa.gov

Marshall Space Flight Center
Selected technological strengths: Materials; Manufacturing; Nondestructive Evaluation; Biotechnology; Space Propulsion; Controls and Dynamics; Structures; Microgravity Processing.
Sally Little
(256) 544-4266
sally.little@msfc.nasa.gov

Stennis Space Center
Selected technological strengths: Propulsion Systems; Test/Monitoring; Remote Sensing; Nonintrusive Instrumentation.
Kirk Sharp
(228) 688-1929
kirk.sharp@ssc.nasa.gov

NASA-Sponsored Commercial Technology Organizations

These organizations were established to provide rapid access to NASA and other federal R&D and foster collaboration between public and private sector organizations. They also can direct you to the appropriate point of contact within the Federal Laboratory Consortium. To reach the Regional Technology Transfer Center nearest you, call (800) 472-6785.

Joseph Allen
National Technology Transfer Center
(800) 678-6882

Ken Dozier
Far-West Technology Transfer Center
University of Southern California
(213) 743-2353

Dr. William Gasko
Center for Technology Commercialization
Massachusetts Technology Park
(508) 870-0042

J. Ronald Thornton
Southern Technology Applications Center
University of Florida
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Gary Sera
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Lani S. Hummel
Mid-Atlantic Technology Applications Center
University of Pittsburgh
(412) 383-2500

Chris Coburn
Great Lakes Industrial Technology Transfer Center
Battelle Memorial Institute
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NASA ON-LINE: Go to NASA's Commercial Technology Network (CTN) on the World Wide Web at **http://nctn.hq.nasa.gov** to search NASA technology resources, find commercialization opportunities, and learn about NASA's national network of programs, organizations, and services dedicated to technology transfer and commercialization.

NASA Program Offices

At NASA Headquarters there are seven major program offices that develop and oversee technology projects of potential interest to industry. The street address for these strategic business units is: NASA Headquarters, 300 E St. SW, Washington, DC 20546.

Carl Ray
Small Business Innovation Research Program (SBIR) & Small Business Technology Transfer Program (STTR)
(202) 358-4652
cray@mail.hq.nasa.gov

Dr. Robert Norwood
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rcrouch@hq.nasa.gov

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Office of Mission to Planet Earth (Code Y)
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gpaules@mtpe.hq.nasa.gov

NASA's Business Facilitators

NASA has established several organizations whose objectives are to establish joint sponsored research agreements and incubate small start-up companies with significant business promise.

Wayne P. Zeman
Lewis Incubator for Technology
Cleveland, OH
(216) 586-3888

B. Greg Hinkebein
Mississippi Enterprise for Technology
Stennis Space Center, MS
(800) 746-4699

Julie Holland
NASA Commercialization Center
Pomona, CA
(909) 869-4477

Bridgette Smalley
UH-NASA Technology Commercialization Incubator
Houston, TX
(713) 743-9155

John Fini
Goddard Space Flight Center Incubator
Baltimore, MD
(410) 327-9150 x1034

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(408) 557-6700

Marty Kaszubowski
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If you are interested in information, applications, and services relating to satellite and aerial data for Earth resources, contact: Dr. Stan Morain, **Earth Analysis Center,** (505) 277-3622.

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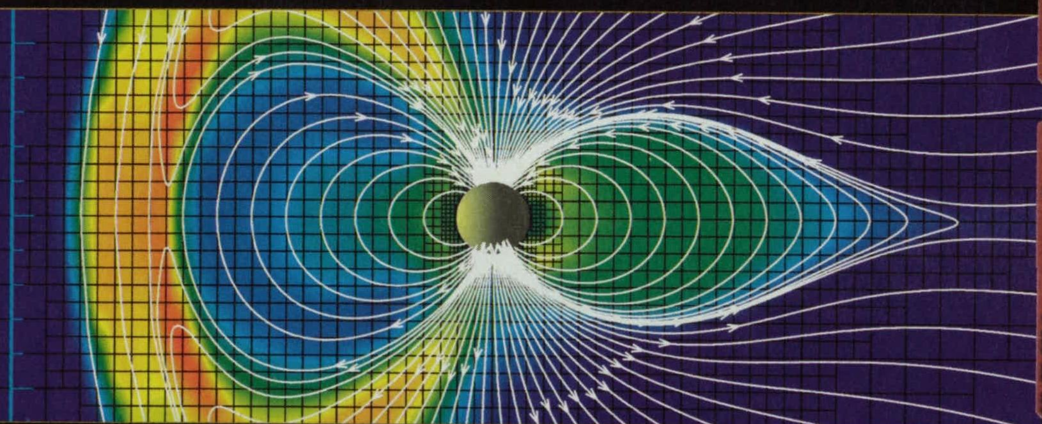

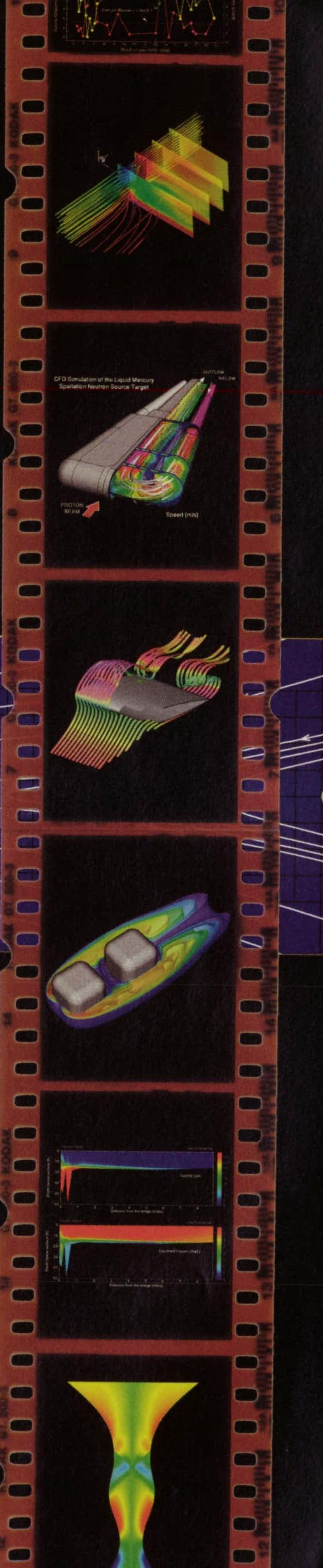

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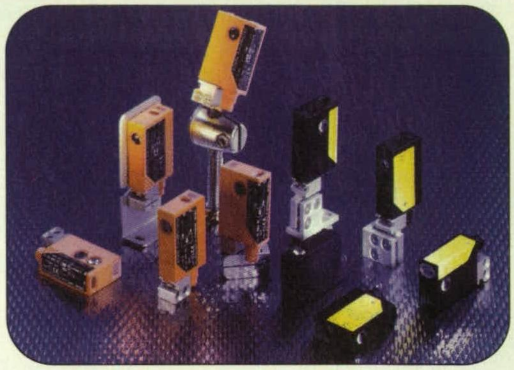
UpFront

PRODUCT OF THE MONTH

The OJ series of miniature photoelectric sensors from ifm efector, Exton, PA, features automated setup and calibration, and either a visible light or a laser light source. Two configurations provide the lens on the face sensing or side sensing surfaces. The sensors include a microprocessor that provides signal processing and analysis capabilities. During initial installation, a pushbutton calibration procedure allows the sensor to learn the signal characteristics of both the target and the background. It then automatically adjusts its range to provide a maximum safety margin under both the target-present and target-not-present conditions. The sensor continuously monitors the strength of the received signal and provides a visual warning if marginal conditions exist. All models include a quick-disconnect mounting feature that allows sensor replacement without disturbing the mounting bracket, eliminating the need to realign the sensor.

For More Information Circle No. 740



The Votes Are In

Thanks to all of our readers who voted for the 2000 Readers' Choice Product of the Year Awards. Your votes have been counted — and recounted! — and the winners are:

Gold Winner and Product of the Year

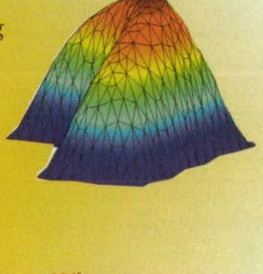
Century-C/M computers and monitors from **Computer Dynamics** (Greenville, SC)

TECH BRIEFS 2000 Product of the Year

Silver Winner

FEMLAB multiphysics modeling and analysis software from **COMSOL** (Burlington, MA)

TECH BRIEFS 2000 Product of the Year



Bronze Winner

IESP/IESF miniature pressure sensors from **CUI Stack** (Beaverton, OR)

TECH BRIEFS 2000 Product of the Year

The awards were presented during a special reception held in conjunction with the National Design Engineering Show in Chicago. Look for highlights of the awards reception in next month's issue.

Biometrics Come to NASA

Computer security has become an important issue for all government agencies, including NASA, especially after reports of hackers breaking into government web sites and databases. NASA has begun evaluating biometrics log-in technologies to safeguard its computer systems. Biometrics includes scanning of fingerprints, retinal scans, facial recognition, or a combination of the three, to prevent unauthorized access.

NASA's Goddard Space Flight Center in Greenbelt, MD, is testing the eTrue authentication service from eTrue Inc. of Southborough, MA, that uses small cameras and fingerprint scanners, and stores the users' data on servers. The service also can perform iris matching and voice recognition. Goddard employees currently use a combination of passwords and key cards to secure their computer rooms and terminals. NASA also is testing the Internet as a way of sending and validating biometrics data.

Controlling operations in space — and ultimately controlling the Space Shuttle — from the Internet can cut costs, but also increases the possibility of someone locating those operations and changing the course of spacecraft. Web-based control of objects in space already has been tested successfully by Lockheed Martin, which used a Palm VII and a laptop computer to command a communications satellite.

For more information, contact Goddard's Public Affairs Office at 301-286-8955; e-mail: gsfcpao@pop100.gsfc.nasa.gov.

Reader Forum

Reader Forum is dedicated to the thoughts, concerns, questions, and comments of our readers. If you have a comment, a question regarding a technical problem, or an answer to a previously published question, post your letter to Reader Forum on-line at **www.nasatech.com,** or send to: Editor, *NASA Tech Briefs*, 317 Madison Ave., New York, NY 10017; Fax: 212-986-7864. Please include your name, company (if applicable), address, and e-mail address or phone number.

The brief "Parabolic Membrane-Thickness Variation for Inflatable Mirror" in the January issue (page 62) included a figure that shows an open cylinder containing a fluid rotating to produce a parabolic surface on the fluid. This, essentially, is a vortex in an open cylinder. Since only a forced vortex with constant angular velocity will produce a parabolic surface, the means of producing the constant angular velocity of stream lines is important. In the article, the author states that this technique has been used to make astronomical mirrors. Could the authors supply a reference showing how these mirror fabricators made the streamlines rotate at a constant angular velocity?

A.M. Cooke
Carson City, NV
775-885-8854

*(**Editor's Note:** A.M., the first place to look for an answer to your question is the Technical Support Package (TSP) available from the authors, Aden and Marjorie Meinel of NASA's Jet Propulsion Laboratory. You can access that information by going to the www.nasatech.com web site and clicking on Technical Support Packages. If you do not have web access, you can contact JPL's Commercial Technology Office at 818-354-2577, and they can put you in touch with the authors.)*

About a year ago, I read a brief in *NASA Tech Briefs* about using DC current and salt water to electrolytically pit the surface of titanium as a proposed alternate method to various acid etches used in preparation for adhesive bonding. Now that I have the budget to investigate alternate Ti surface preparations, I no longer have the brief. Can you help me find this information?

Mike Hall
mike.hall@boeing.com

*(**Editor's Note:** Mike, that article appeared in the April 1999 issue of NTB, and was entitled, "Electric-Arc and Electrochemical Texturing of Surfaces," by Bruce Banks and Sharon Rutledge of NASA's John Glenn Research Center in Cleveland. For a copy of the brief, go to www.nasatech.com, click on Tech Briefs, and look for the April 1999 issue. There you'll find the complete brief and the link to its Technical Support Package.)*

Get Connected With "Quick Quotes"

You may have read in last month's issue about the launch of our new Web marketplace called "Quick Quotes." In case you missed the announcement, Quick Quotes connects buyers and suppliers of custom manufacturing and engineering services — machining, molding, casting, rapid prototyping, reverse engineering, product design, finite element analysis, and much more. The new site — **www.nasatech.com/quickquotes** — accesses the MfgQuote Marketplace created by ManufacturingQuote Inc. (Smyrna, GA), a leading eProcurement platform provider.

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Quick Quotes does not charge a commission on jobs placed, but rather a flat membership fee. Buyers can post RFQs free of charge and without obligation. Visit **www.nasatech.com/quickquotes** to learn more.

Dr. G.D. Arndt, Technical Assistant, Avionics Systems Division, Johnson Space Center

Dr. G.D. (Dickie) Arndt is Technical Assistant in the Avionics Systems Division at NASA's Johnson Space Center in Houston, TX. Dr. Arndt, along with electronics engineer Patrick Fink, has developed a means of using millimeter-wave and microwave ablation to treat diseased coronary arteries without injuring them.

***NASA Tech Briefs*: How did NASA get involved in this project?**

Dr. Dickie Arndt: Several years ago, two doctors from the Houston Medical Center came to Johnson to get NASA's help in developing catheters for several different projects. The first one we worked on was with Dr. Anthony Pacifico for treating ventricular tachycardia, which means rapid heartbeats. The other doctor, Philip Henry, who specializes in atherosclerosis problems, found that our tachycardia system worked well, and suggested that we come up with a catheter to treat atherosclerosis, where lesions and plaque build up and clog the arteries.

NTB: What is the connection between the Avionics Division and coronary artery disease research?

Dr. Arndt: A few years ago, NASA combined the Avionics Division with the Communications Division, which we were part of. We worked on communications systems, microwaves, and antennas. We were asked by Johnson's Life Sciences group to support some testing that they wanted to do. They had equipment leased out that could extend frequencies beyond what we had equipment for here. That program finished early, and the lease for the equipment was still in effect. We tried to brainstorm any possible applications for which we might use the equipment. Somehow this idea came up.

NTB: What components make up the system, and how does it work?

Dr. Arndt: The catheter is a cable, and we have a little antenna on the end of the cable. The antenna can be different configurations, depending on the frequency. We have a signal generator that puts out fairly high frequency, and we have a little antenna on the end of it. The energy from the microwave generator is sent out and goes down the catheter, and the electromagnetic energy is radiated through the antenna. It runs into the body tissue, where the heat travels in two ways: it propagates through the body tissue until it's absorbed, but you also have thermal induction, in which you heat up the tissue close to the surface and it propagates away through thermal conductivity.

NTB: Why is use of this system better than the current treatments available?

Dr. Arndt: You can put balloons or stints in the arteries, but both of them have essentially the same problem — you damage the inside of the artery when you try to get rid of the fatty build-up. The platelets and white corpuscles then try to cover the injury. They're doing exactly what you don't want them to do, which is re-building the tissue where you've already treated it. That's the reason that probably 50% of the people who have angioplasty have to have it done again within a year or so. Dr. Henry's idea was that if we could heat up the plaque and fatty tissue with microwave heat, maybe we could flow it away, and at the same time, keep the artery from being damaged. We worked on catheters of different frequencies.

I would think this system has less impact on the human body than angioplasty, in which you're actually opening something and crushing the plaque. With our system, you're just heating up a small region of the artery.

NTB: Are there other applications for this method besides treating coronary artery disease?

Dr. Arndt: There has been talk about using it to treat tumors. If you could heat up the tumor 10 or 20 degrees, you would essentially cook the cells and kill them. We are looking at a variation of this for prostate cancer. They already do a "cooking" of the prostate to treat cancer, so if you could position the catheter precisely, you could do the same with this system.

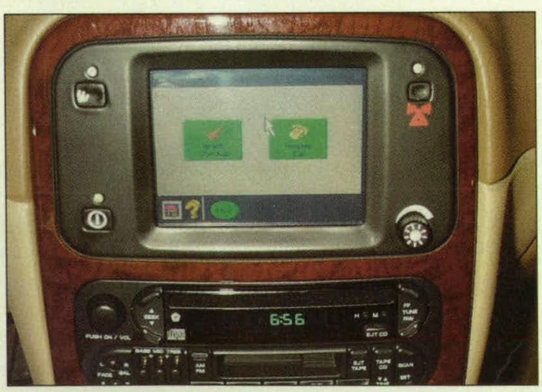
*A full transcript of this interview appears on-line at **www.nasatech.com**. Dr. Arndt can be reached at g.d.arndt1@jsc.nasa.gov.*

New Technologies Drive Changes in Auto Design and Production

Whether we like it or not, the amount of time most of us spend in our cars continues to rise. As a result, we want our vehicles to not only get us from home to work and back, but also to provide comfort and convenience during the ride. We need to be productive in the car, but we also want to be entertained. Auto makers and their suppliers are trying to accommodate both requests with new technologies that enable drivers and passengers to stay connected to the non-mobile world. And those new innovations mean that automotive design engineers need their own new technologies to keep up with consumers' demands.

Designers are now faced with incorporating into their car designs voice recognition, automated collision avoidance, infrared-laser night vision, "infotainment" systems, and in-vehicle concierge services. What was once a question of whether or not to get air conditioning is now a question of whether to get personalized stock quotes or a rear-seat video system.

"Cars are being designed completely differently than a few years ago," said Rishi Madabusi, global business development manager for IBM's Product Lifecycle Management (PLM). "Design engineers used to design a car, whether it was a Mustang or a Beetle. Now, they have to design a station wagon, an SUV [sport-utility vehicle], a two-door, a convertible, and a four-door sedan at the same time." Design engineers don't have time to design five or six different cars, he explained, so they design five or six different variations to cover the spectrum of the marketplace.



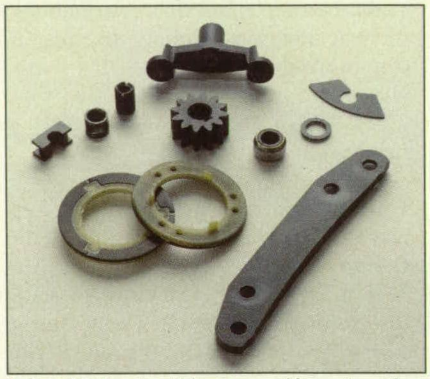
If a car becomes disabled, IBM's off-board computing software automatically calls for roadside assistance, and downloads a diagnostic "health check" report into the computer system of a nearby service station. When the car is brought in for service, the station knows exactly what needs to be fixed.

One of the most important tools used by designers is CAD/CAE software. But, in the auto industry, it goes well beyond just CAD. Product data must be leveraged beyond the CAD product to provide "process coverage." Explained Madabusi, "Process coverage extends well beyond conceptual design into maintenance, service, and retirement of the product. If you look at most of our automotive customers using CATIA [CAD software], they don't just do body design. They do exterior/interior trim, power trains, the chassis, the entire sheet metal structure, and the electronic aspects of a car." In addition, he said, auto makers like DaimlerChrysler are even using it to design the manufacturing facility itself. They use the software for robotic simulation to make sure that the pinstripe on the side of the car can be done in the allotted time the car stays in the paint shop.

So have advanced CAD capabilities affected the way cars are designed? The tools give users the ability to show "what-if" scenarios, and thus, to design the vehicles to operate better. "With the kinds of design tools available today," said Madabusi, "you can vaguely design the shape of the hood, put some lights on top to test reflections, and poke and pull and change the shape. You can see things change in real time. And this is not on a specialized graphics workstation."

John Mowrey, vice president of professional services for MSC.Software in Southfield, MI, agrees that automotive design today is a different process, starting from the very beginning. "We used to do everything with hand renderings. Now, a good share of the work is done right on the computer with visualization software."

Mowrey points out that computers and simulation software are being used in applications today that could not be imagined 20 years ago. "Computer simulation is used extensively now in applications such as ride and handling, structures and durability, crash worthiness, acceleration and braking performance, and engines and linkages. There have been dramatic changes that have taken place in every one of these areas, and in what computer simulation has done for us," said Mowrey.


DuPont Engineering Polymers provides auto makers with Vespel parts and shapes, such as bushings, gears, washers, and wear strips.

Design, as a result, affects manufacturing. The automotive model year seems to become shorter each year, requiring auto makers to manufacture better cars in less time at a lower cost, while still meeting safety requirements. According to Madabusi, that means more pressure on personnel all along the manufacturing chain. "There are more electronics, more computers, GPS systems, and telematics. That kind of packaging and infusion of technologies makes the design more complicated." For example, he asked, "Ten years ago, did you have to worry about an LCD panel lasting five years in a car?"

DaimlerChrysler's senior technology manager, Phares Noel, indicated that the auto maker is trying to reduce to 12 months the time from the initial "paper-napkin" design to volume production. "The development cycle or time to market from concept to final production is shrinking," he said. "The challenge is having a manufacturing system that's flexible enough so that you can make different products within the same facility."

(Continued on page 20)

Always in Touch

Imagine the convenience of being able to verbally pre-order your groceries as you're driving to the store, or make a reservation at your favorite restaurant without having to fumble for the number and dial your cell phone. Based on hands-free, voice-activated operation, telematics and other new technologies being designed into cars combine safety and convenience.

Ten years ago, not many people had ever heard the word telematics. Now it is the focus of every major car maker, technology companies like IBM, and automotive industry suppliers such as Delphi Automotive Systems. Telematics is the term commonly used to describe in-vehicle information centers. The first generation of telematics was OnStar, General Motors' satellite-linked assistance service that enables a driver to push a button and be connected instantly to an emergency call center/information center. Today, GM provides OnStar Virtual Advisor, which not only offers directions and road assistance, but uses voice-command controls for telephone dialing and Internet access.

Understandably, the in-vehicle entertainment options telematics provides are the most attractive aspects for many consumers. But telematics, based on voice-recognition, is focused on safety — keeping the driver's hands on the wheel while he or she performs a variety of other tasks simply by speaking. Using global positioning system (GPS) satellite communications and sophisticated in-vehicle sensors, these systems can detect if your airbag has been deployed, if your car has broken down, or if your water pump is about to fail. The system automatically can call you to see if you are injured, and will dispatch a 911 call if necessary.

According to Raj Desai, director of worldwide automotive solutions for IBM, telematics is one of the top five initiatives of all the top auto makers. "The big ones," he said, "are looking at it in a big way, and the small ones are looking at it in a collaborative way, either with the larger ones or among themselves."

Desai predicts that in the near future, telematics will be invisible. "A technology explosion has taken place, wireless technology is improving every year, bandwidth is going up, and all of these changes have created a new class of devices that don't look like computers. In the future, the place where you do e-business won't have to be a computer like we know it today with a keyboard."

The primary role IBM plays in telematics is ViaVoice, its voice recognition technology. The company's WebSphere Everyplace Suite is the software that manages the underlying server network. Today's telematics systems, said Desai, need to be automated and have an open architecture to attract software developers to write applications. "The lifecycle of telematics technology is anywhere from three to 18 months. Things become obsolete if it takes two to three years to deliver a car, and it stays on the road for eight to ten years."

Sensory, a provider of speech recognition technology, also is getting into the telematics game with its Interactive Speech line of integrated circuits that can perform speech/audio functions such as speaker verification, speech and music synthesis, voice record and playback, and continuous listening. Sensory also offers Voice Activation software, which provides a limited vocabulary, and Fluent Speech Recognition software, which has a larger vocabulary of up to 50,000 words.

According to Erik Soule, Sensory's director of marketing, the auto-buying public is not aware of the technology that's available in the area of telematics. "They don't know what they want. If you told people 20 years ago that every car some

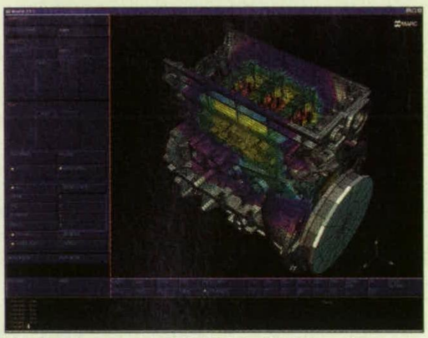
day would have power locks and windows, they'd say, 'How hard is it to turn the crank?' But every car has them now, and people won't buy a car without them." Soule anticipates that companies may misapply the technology.

"You don't want to voice-activate everything in the car — it's frivolous." There is a real need, for example, for a navigation system to be voice-activated, especially if you're trying to give an address without entering it into a keypad — a huge distraction in the car, said Soule.

What They're Made Of

Telematics is not the only thing affecting the way vehicles are designed. The materials that make up cars are changing rapidly, forcing designers to consider how more plastics, composites, and other lighter weight materials will affect a vehicle design.

And, again, design affects manufacturing. Said DaimlerChrysler's Noel, "When we start using more plastics, and especially when we start painting them, that's a real challenge. Usually we'd be able to paint everything in one area, and now you can't." Some materials, for example, cannot be put into ovens and subjected to high drying temperatures.



This engine was modeled with MSC.Marc finite element software for engineering simulation from MSC.Software.

Companies that supply parts and materials to the auto industry, such as DuPont and GE Plastics, face the challenges of matching appropriate materials to the application requirement, and keeping cost and weight down. DuPont's Engineering Polymers Division manufactures the Vespel® Parts and Shapes line, which consists of five families of polyimide, composite, chemical-resistant, and thermoplastic materials. Their focus is supplying parts for drive line systems — anything from the back of the engine through the rear axle — and for small motors used in window lifts, seat adjusters, and windshield wipers.

Richard VanRyper, senior development engineer at DuPont Engineering Polymers, explained that systems are getting smaller and weighing less, but the requirements on the parts continue to grow in terms of their load-carrying capabilities and temperature extremes. "When you get into using a variety of different materials, there are a couple of things that come to mind. We're seeing more reliance on the supplier to demonstrate the capability of a product," said VanRyper.

Suppliers like DuPont need to know more than just the current requirements of the auto industry. They need to know where the industry will be five years from now. "There are new materials under development today to meet certain requirements," said VanRyper. Too often, he explained, the link between research on new materials and their commercialization is too wide. "We, as a supplier, look back to the R&D functions within the product line we deal with, as well as what's being developed, to be sure we're not missing something that may come along."

What the Web Brings

The amount of automotive engineering being done by suppliers, rather than within the OEMs, continues to increase, as does the number of suppliers. The Chrysler group of DaimlerChrysler, for example, has more than 900 production suppliers. OEMs want to be systems integrators, putting the total vehicle together after suppliers have provided complete assemblies. Auto makers, therefore, are farming out more of their engineering work to the suppliers. The problem is that some of those suppliers don't necessarily have the engineering expertise, according to MSC's Mowrey. "Now, suppliers are being asked to do the concept, the design, the engineering, the testing, and the validation on all the parts they supply."

IBM's Madabusi estimates that anywhere from 75 to 80 percent of a car is designed by somebody other than the OEM. "The way to get a digital mockup to work in a general environment is to provide a Web-based interface to all this product information in a single portal so the users can put a brake assembly together on the Web and share it with others," he explained.

Data sharing within the auto industry has the same risks and benefits as in many other industries. Protecting proprietary information, having properly trained personnel using the right software, and maintaining the underlying databases all must be considered when looking at Web-based collaboration.

"If you have an engine-mounting system to design, you can probably do that in China or India or Brazil as well as you


IF YOU CAN THINK IT, WE CAN DO IT.

could in Detroit, if it's properly specified and the scope of the work is properly identified," said Mowrey. But while it sounds good in principle, he warns that auto makers are struggling with such collaboration. "In these remote areas, while they may have the computer software and hardware, they don't have the people experienced in using it, and their people don't have firsthand knowledge of how vehicles and vehicle systems operate physically. Just being able to do an analysis is not really enough to become a full engineering supplier," Mowrey added.

Covisint is the online trade exchange for auto makers and their suppliers that was first announced in February 2000. The exchange was designed to handle online parts auctions, product development, and supply-chain management. The initiative's participants include General Motors, Ford Motor, DaimlerChrysler, Renault SA, and Nissan Motor. The five companies have a combined purchasing budget of $300 billion per year.

Covisint offers its participants the opportunity to hold "reverse" auctions in which the customer invites several vendors to bid for the right to supply commodity parts such as hoses and gaskets. After an hour of bidding, the company with the lowest bid wins. DaimlerChrysler's Noel sees the exchange as a leveling device for competition among the "Big 3" auto makers. "We'll all be able to purchase equipment or components in a very large market space with a lot of competitors. All of us will win; that's why all of us got together on this. It's good for us as OEMs because we'll get a cheaper price, and it's good for the vendors because they're going to get huge orders."

The auto industry faces the challenges of keeping their supplier network connected, as well as providing their own design and manufacturing teams with the tools they need to put the latest innovations into today's cars. Said Madabusi, "If we can go seamlessly from the virtual to physical worlds, there's only one enemy in this equation, and that's time. With enough time, you can design just about anything better than anybody else."

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April 2001

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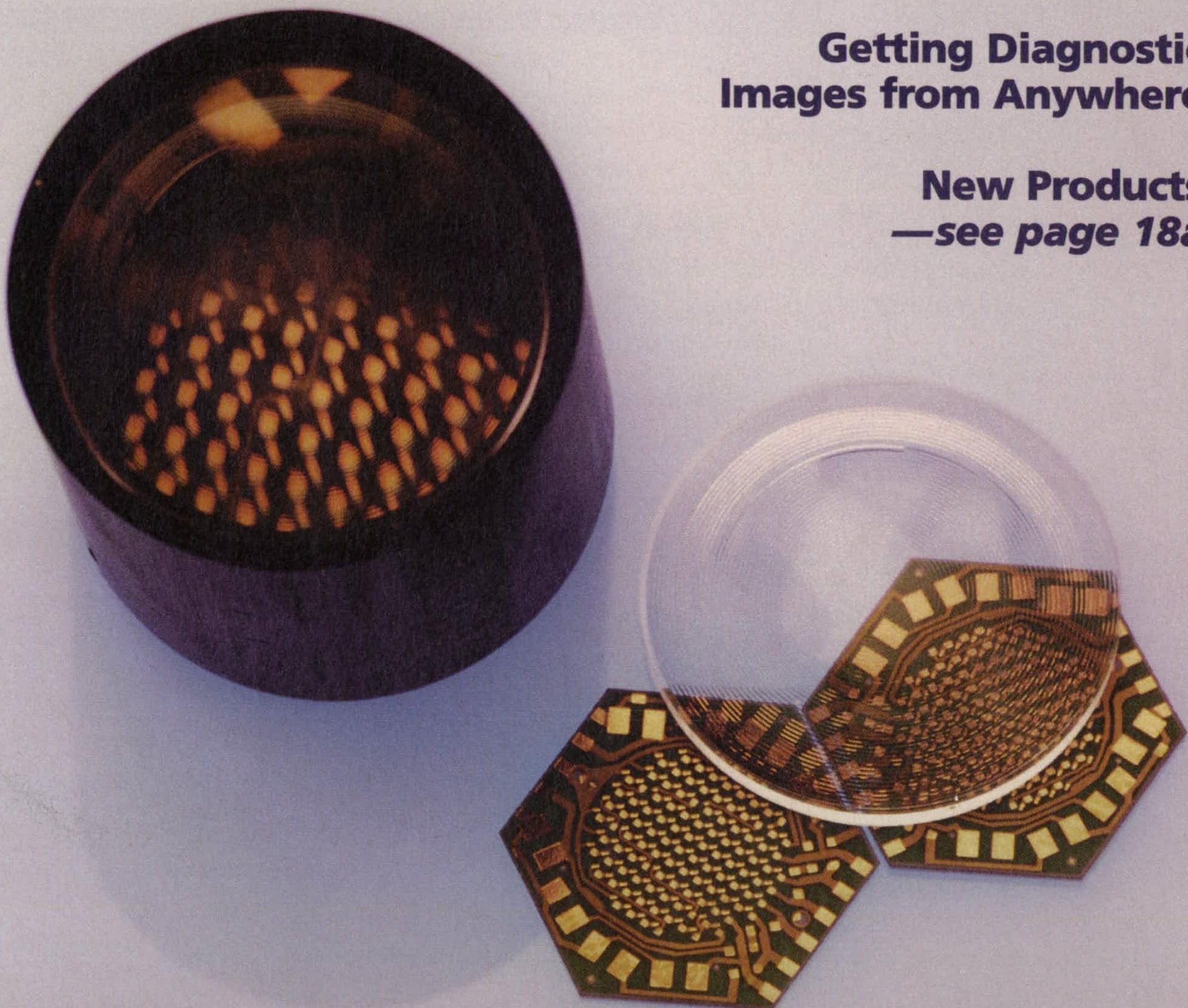

Getting Diagnostic Images from Anywhere

New Products
—see page 18a

In the Briefs Section:

Confocal Fiber-Optic Raman Microspectrometer

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Supplement to *NASA Tech Briefs'* April 2001 Issue Published by Associated Business Publications Intl.

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Tech Briefs

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18a New Products

On the cover: *StockerYale's LED area light contains 88 chip-on-board LEDs combined with a single lens to give a diverging beam of light.*
Cover photo courtesy of StockerYale.

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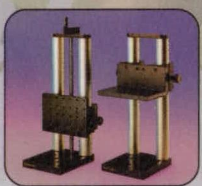

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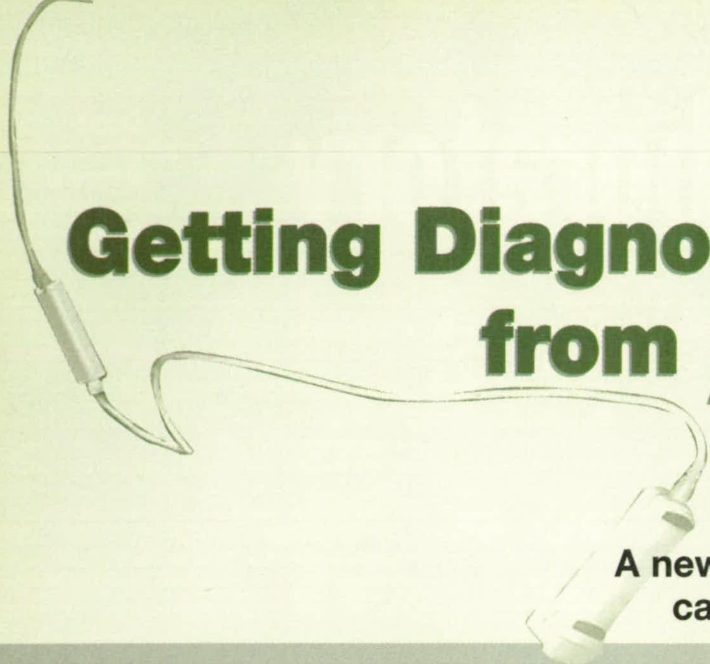
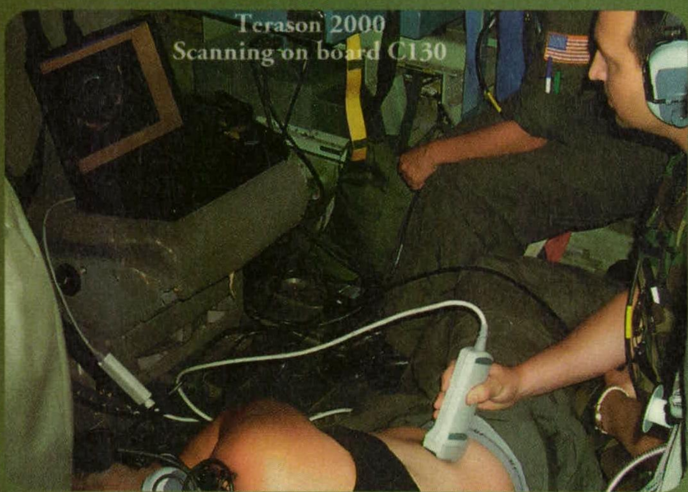


A new miniature instrument from Terason can even transmit high-quality images from a plane in flight.



Dr. Michael Freckleton performs a scan with the Terason 2000 handheld ultrasound diagnostic system in an Air Force C-130.

The Teratech Corporation's Terason Division (Burlington, MA), which provides high-resolution miniaturized medical ultrasound imaging systems implemented on standard PC architecture, supplied a new probe used in a pathbreaking medical experiment. Dr. Michael Freckleton, director of the medical imaging and information projects office in the Department of Engineering at Texas A&M University used the Terason microminiature ultrasound system, called SmartProbe, to transmit live digital images from an Air Force C-130 in flight to a medical team on the ground. The team on the ground was very impressed with the quality of the images. As Freckleton put it, "The image quality was excellent, with no perceptible image degradation despite a very noisy, bumpy plane."

Unexpectedly, too, the experiment turned out to prove more than the utility of the instrument. The doctors diagnosed multiple gall stones in the "patient," the load master of the C-130, who was completely unaware of his condition until the exam.

The Air Force team, already experienced with the Terason system-on-a-chip technology, wanted to test it in flight, and so Dr. Freckleton was asked to take the system up in the plane and to do an ultrasound exam to send back to medical and engineering personnel on the ground. Kerr Spencer, senior vice president of marketing and sales at Terason, described the results this way: "It was a successful first run for air-to-ground telemedicine, a demonstration of the vast implications for patient accessibility using this system."

The Terason 2000 handheld ultrasound system used in the test consisted of a curved-array Terason SmartProbe connected to a notebook PC. Spencer says it is the first ultrasound system to make diagnostic imaging an intuitive PC application. The Terason system can store tens of thousands of digital images on line and export them via DICOM-compatible technologies, making it suitable for use in networks and telemedicine.

"Its plug-and-play PC options speed ultrasound exams," Spencer said, "and allow them to be performed virtually anywhere rapid diagnostic decisions are needed."

Dr. Freckleton was also involved in an earlier test, scanning "patients" in a tent in the desert north of Las Vegas. In a demonstration for Special Operations personnel and Air Force medical officers, images were downloaded through an S-video cable, sent up to a Ku-band satellite and back to a C-130 aircraft with special antennas. They were then beamed down to a medical team at the Nellis Air Force Base in Nevada, who described them as having "diagnostic image quality as good as the best we've seen with conventional systems." Additional testing will take the participants to the Mediterranean in cooperation with a Marine unit.

Teratech Corporation has worked with the U.S. Department of Defense for many years to develop sonar systems and portable imaging systems for the Army's Telemedicine and Advanced Technology Research Center. Led by Teratech's president, Dr. Alice Chiang, the Terason

team invented powerful charge-domain processing (CDP) computing circuits that were very small and operated at high speed with extremely low power and great precision. Turning to medical applications, they decided that ultrasound was the place to start. The result was the Terason 2000, the ultraportable ultrasound system in a probe, an innovative "plug-and-play" system that uses existing PC platforms to give medical personnel greater access to patients in virtually any setting and to enhance diagnosis through superb image quality comparable to that of larger conventional systems.

For more information, please contact Kerr Spencer at Teratech; 781-270-4143.

TERASON 2000

Handheld Ultrasound System

The Terason 2000 handheld ultrasound system was the subject of an invited paper at last fall's IEEE Conference of the Ultrasonics, Ferroelectrics and Frequency Control Society in San Juan, Puerto Rico. At a poster session titled "PC-based Ultrasound Imaging System in a Probe," Terason demonstrated the miniature ultrasound system with its 10-ounce Terason SmartProbe™ linked to a standard off-the-shelf PC. The company calls the system the first to make ultrasound an intuitive PC application. It was demonstrated with both 2.5-MHz phased and 5-MHz curvilinear array SmartProbes running on palmtop and high-end laptop PCs.

Terason says the presentation drew attention to its proprietary technology called charge-domain processing (CDP), which features a chip with great computational capability, low power consumption, and easy integration into operating systems. The result is the Terason 2000 system, a high-performance ultrasound system housed in the scan probe, readily linked to a variety of host PCs, and able to take diagnostic imaging to any point-of-care setting.

Other highlights of the IEEE conference included sessions on ultrasound contrast agents and imaging techniques, cardiac elastography, therapeutic ultrasound, high-frequency ultrasound, and array transducers.

PHOTONICS *file*

Recent photonics briefs published in NASA Tech Briefs

Many photonics-related briefs from NASA's field center laboratories appear in *NASA Tech Briefs* rather than in the *Photonics Tech Briefs* supplement. Listed here are some from issues of *NASA Tech Briefs* just past, edited for brevity and indexed with reference to original publication and the availability of a Technical Support Package on *Photonics Tech Briefs'* web site.

NASA Tech Briefs *January 2001, page 62*

Parabolic Membrane-Thickness Variation for Inflatable Mirror *(NPO-20952)*

According to a proposal, membranes to be used in inflatable focusing mirrors would be designed and fabricated with parabolic radial variations of thickness. The reason for this proposal is that by suitable choice of a parameter described in the brief one could insure that upon inflation the membrane would assume a shape that closely approximates a paraboloid — the shape required for focusing in many applications. Although there have been suggestions that radial variations in thickness might result in inflated shapes that equal or closely approximate paraboloids, the necessary variation in thickness has not been published until now.

For further information, access the Technical Support Package (TSP) ***free on-line at www.ptbmagazine.com*** *under the Mechanics category.*

NASA Tech Briefs *January 2001, page 36*

Submillimeter-Wave Image Sensor *(NPO-20718)*

A proposed monolithic planar array of miniature dipole antennas, diodes, and associated input/output circuitry would serve as a prototype of image sensors for submillimeter-wavelength video cameras. Sensors of this type could be designed to operate as either direct or heterodyne detectors of electromagnetic radiation at frequencies from 300 GHz to 3 THz; as such they could offer new capabilities for such diverse uses as analysis of submillimeter radiation from far-infrared devices, measurements of the submillimeter-wavelength radiative properties of materials, molecular-line spectroscopy of astronomical bodies and the upper atmosphere of the Earth, and perhaps imaging of biomaterials for medical applications.

For further information, access the Technical Support Package (TSP) ***free on-line at www.ptbmagazine.com*** *under the Electronic Components and Systems category.*

NASA Tech Briefs *November 2000, page 36*

Software for Multidisciplinary Analysis of Optical Systems *(NPO-20536)*

Integrated Modeling of Optical Systems (IMOS) is a MATLAB™ computer program that provides many functions for analysis of a system represented by mathematical models of its thermal, structural, control, and/or optical aspects. The uniqueness of IMOS lies in the possibility of performing the entire analysis in one program. IMOS provides interfaces between itself and several other programs.

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NASA Tech Briefs February 2001, page 40

Measurement of Stresses and Strains in Muscles and Tendons *(NPO-20464)*

Miniature fiber-optic-coupled sensors based on optically excited, self-resonant microbeams are being developed for measuring stresses and strains within muscle fascicles and tendons. These sensors could be used in medical and biological research on humans and other animals, or to obtain data for the design of lifelike robots. Each sensor has typical dimensions of about 1 by 1 by 0.1 mm. These dimensions are suitable for surgical implantation in muscle and tendon tissues; these dimensions are also comparable to diameters of cores of multimode optical fibers, making the sensors amenable to fiber-optic coupling. The stress could be applied to the sensor via fibers or ribbons attached to a tendon. If the sensor is to be used to measure strain in a tendon, then both fibers or ribbons must be nonextensible and are attached to the tendon. If muscular tension is to be measured, then both fibers or ribbons must be nonextensible and attached to the loose ends of a severed tendon.

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Leakage-Preventing Design of Snapshot Photodiode CMOS Imager

Other improvements would include increased fill factor and reduced readout noise.

NASA's Jet Propulsion Laboratory, Pasadena, California

A new design for a complementary metal oxide/semiconductor (CMOS) snapshot imaging device of the photodiode-based, active-pixel-sensor (APS) type calls for features to prevent photogenerated electric charges collected during a given frame period from leaking into in-pixel capacitors that store charges collected during the preceding frame period, pending completion of readout from that period. The proposed design would also utilize the electronic-shuttering capability of an APS to provide for programmable exposure time, down to (≈10 μs) a small fraction of the frame period, to enable faithful recording of images of rapidly moving objects. Finally, the design would make it possible to obtain quantum efficiency higher and readout noise lower than those of a typical prior CMOS APS imaging device.

The circuit in each pixel of a typical CMOS snapshot imaging device (see Figure 1) includes a storage capacitor (C_p) that serves as both a frame buffer memory (as described above) and a sensing node. The photodiode in this circuit converts incident photons to electrons during an exposure time that is defined as the time during which transistor switch RST-D is kept open. The possibility of controlling this time by controlling the duration of a pulse that controls RST-D (in other words, electronic shuttering) is what makes it possible to set the exposure time at any desired fraction of the frame period.

During the exposure, photoelectrons are stored temporarily in the photodiode capacitance (C_d). After the exposure, C_p is reset (that is, purged of the charge from the preceding frame period) by momentary closing of transistor switch RST-C. During this reset, part of the charge accumulated in C_d during the just-completed exposure is transferred to C_p by momentarily closing the transistor switch labeled "Share." Once this transfer of charge has been completed, the photodiode is available to begin a new frame exposure, and the charge newly transferred to C_p is held there until it is read out at its assigned time in a row-by-row readout sequence that is completed before the beginning of the next frame period.

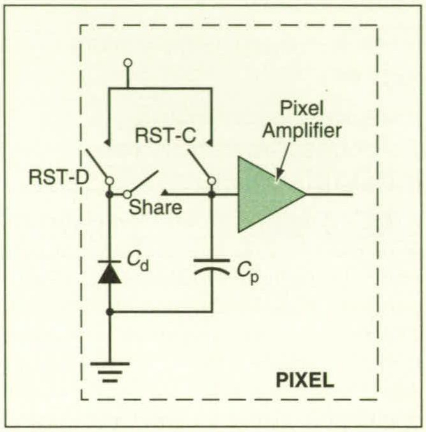

Figure 1. The **Pixel Circuitry** in a CMOS APS imaging device includes (a) a capacitor that acts as a frame buffer memory and (b) provisions for electronic shuttering.

The design and operation of a typical prior CMOS snapshot imager as described thus far raise three main concerns that are addressed by the proposed design:

1. The leakage mentioned above is an unwanted lateral diffusion of charge from C_d to C_p during exposure. This leakage is deleterious because it gives rise to image smear and, in the case of movement in the image, it introduces motion-related artifacts.
2. The transistor switches and the storage capacitor in each pixel reduce the fill factor (the fraction of pixel area devoted to photodetection), thereby reducing quantum efficiency.
3. Readout noise includes significant contributions from resetting of C_p, resetting of C_d, and sharing of charge between C_p and C_d.

In the proposed design (see Figure 2), the pixel circuit elements would be configured to create an electric field that would prevent the diffusion of photoelectrons into C_p. The design would be implemented in a twin-well process with a lightly doped epitaxial layer to ensure excellent collection of photoelectrons. The n well would act as a photodiode,

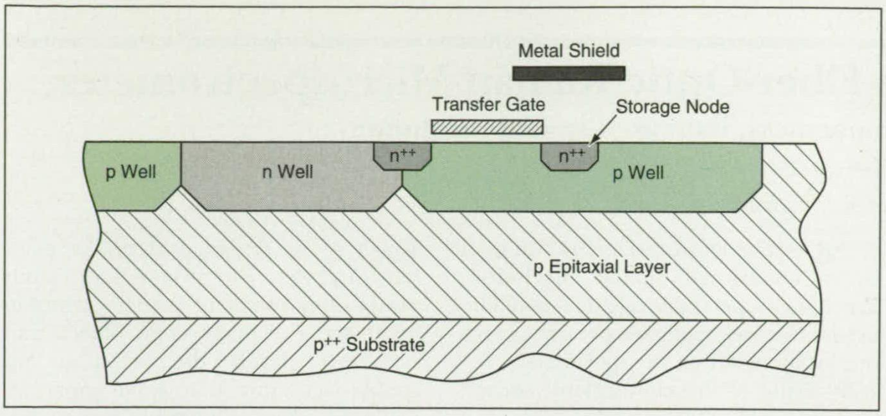

Figure 2. This **Cross Section of a Pixel** according to the proposed design depicts features that would give rise to an electric field that would prevent leakage.

and the storage capacitance would be implemented in the p well as a diffusion or a gate capacitance. The transfer gate would be driven by the "Share" transistor switch as in Figure 1. The storage node would be shielded by metal to maintain the integrity of stored photocharges. The storage node in the p well would be held at ground potential. Hence, electrons generated in the p epitaxial layer or the n well (which would be biased above ground) would be prevented, by the resulting potential barrier, from reaching the storage node. Furthermore, the n^{++}-doped subregion in the storage-node region would be reverse-biased, so that no holes would reach it. Holes would be drained at a p^{++} contact (not shown in the figure) in the p well. Thus, the storage node would be protected against any coupling from the photodiode, enabling smearless imaging.

A major characteristic of this configuration is that the storage capacitance per unit area would be orders of magnitude greater than that in a corresponding prior design, so that it would be possible to make C_p occupy a much smaller area; hence, there would be plenty of margin to choose whatever value of C_p is needed to minimize readout noise, without risk of significantly decreasing the fill factor and thus the quantum efficiency along with it. (The optimum choice of C_p to minimize readout noise turns out to lie between $0.7\times$ and $1\times$ C_d.)

This work was done by Bedabrata Pain of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Components and Systems category.*

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Refer to NPO-21044, volume and number of this NASA Tech Briefs *issue, and the page number.*

Confocal Single-Mode-Fiber-Optic Raman Microspectrometer

Improvements would include compactness, increased spatial resolution, and superior rejection of laser light.

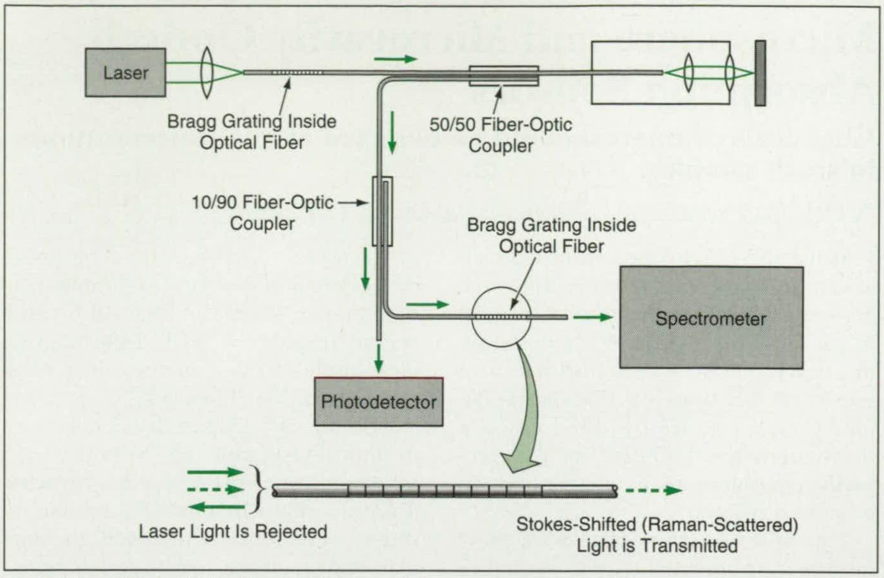
NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed optoelectronic apparatus would perform the combined functions of a confocal microscope and a Raman spectrometer. It would be used to acquire Raman-spectral-image and/or monochromatic-image data from mineral and/or biological specimens with high three-dimensional spatial resolution. The Raman-spectral-image data could be used to identify materials present at various locations within the specimens.

By virtue of the confocal-microscope aspect of its design and unlike prior Raman probes, the proposed apparatus would offer sufficient spatial resolution for imaging of microscopic objects and sufficient depth discrimination to enable sectioning; that is, the apparatus could be used to construct the equivalent of three-dimensional images from confocal-microscope scans in three dimensions. The spectrometer portion of the apparatus would be compact, relative to prior Raman spectrometers of equivalent spectral resolution. The design of the apparatus would also implement a unique solution to the problem of discriminating between Raman-scattered light and laser light used to excite Raman scattering — a difficult problem in that the Raman spectral shift can be small.

The figure depicts one version of the proposed apparatus. Light from a laser or a laser diode would be launched into a single-mode optical fiber configured as an input port (port 1) of a nominal 50/50 fiber-optic directional coupler. One of the output ports (port 3) of the coupler would not be used. Another single-mode optical fiber configured as an output port (port 2) would couple the laser light into a compact scanning head that would contain an objective lens assembly. The light diverging from the output end of this fiber would be focused by the objective lens onto a small spot on the surface of a specimen (or, optionally in the case of a semitransparent specimen, into a small subsurface volume). Light reflected from the specimen (including Raman-scattered light) would be focused by the objective lens assembly into the fiber, where it would travel back toward the 50/50 coupler. The portion of the reflected light coming out of port 4 of the 50/50 coupler would be split by a 10/90 fiber-optic splitter; the weaker output would be sent to a photodetector and the stronger to a Raman spectrometer.

This apparatus would differ substantially from prior Raman probes in which scanning heads are coupled by use of multimode optical fibers. Because of its single-mode nature and small diameter (a few micrometers), the core of the optical fiber ending in the scanning head could be considered a pinhole, which, in combination with the objective lens, would afford the resolution needed



The **Confocal Single-Mode-Fiber-Optic Raman Microspectrometer** would incorporate several improvements over prior Raman probes, including scanning Raman spectrometers that contain multimode optical fibers.

for confocal microscopy with the depth discrimination needed for three-dimensional imaging and spectroscopy of semi-transparent objects. In contrast, coupling by use of multimode optical fibers results in much coarser resolution — both laterally and in depth.

Another important difference between this apparatus and prior Raman probes would lie in the manner of discriminating between Raman-scattered and laser light. In other Raman probes, laser light is often rejected from spectrometer-input paths by use of combinations of notch and edge filters. In the proposed system, a Bragg grating incorporated into the core of the optical fiber going to the spectrometer would serve as a high-resonance-quality (high-*Q*), in-line rejection filter that would block light in a narrow band centered at the laser wavelength while passing the remainder of the spectrum. (A Bragg grating could function in this way only within a single-mode optical fiber; it could not do so in a multimode fiber.) The degree of rejection of laser light could be more than 80 dB.

It would be necessary to compensate for the temperature sensitivities of the narrow-band rejection filter and the laser because if the laser wavelength were to drift from the rejection wavelength, then too much laser light would get through to the spectrometer. The use of fiber Bragg gratings would offer a convenient solution to this temperature-compensation problem: Another Bragg grating, of relatively low reflectivity, located in the optical fiber between the laser and port 1 of the 50/50 directional coupler, would be used to lock the laser wavelength; the laser wavelength would be controlled by the reflection band of this grating, which could be made to match the rejection band of the Bragg grating in the fiber going to the spectrometer. The portions of the optical fibers containing these gratings could be mounted in contact with a common heat sink and thereby maintained at the same temperature.

Yet another notable aspect of the proposed apparatus would be the aforementioned relative compactness of the spectrometer. This compactness would be achieved by a novel design featuring only two reflective surfaces, one of which would be a convex diffraction grating shaped and blazed by electron-beam lithography in poly(methyl methacrylate).

In the version of the apparatus depicted in the figure, the fiber end could be translated along the fast direction of the scan relative to the specimen by use of a microelectromechanical (MEM) scanning mechanism. In an alternative version, the fiber end would be held stationary and a MEM scanning mechanism within the head would translate a small scanning corner reflector that would function in conjunction with a stationary folding mirror and an objective lens assembly. The other directions of the scan can be provided by ordinary piezoelectrics or other means.

This work was done by Pantazis Mouroulis, Mehdi Vaez-Iravani, and Frank Hartley of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category. NPO-20932*

Microsphere and Microcavity Optical-Absorption Sensors

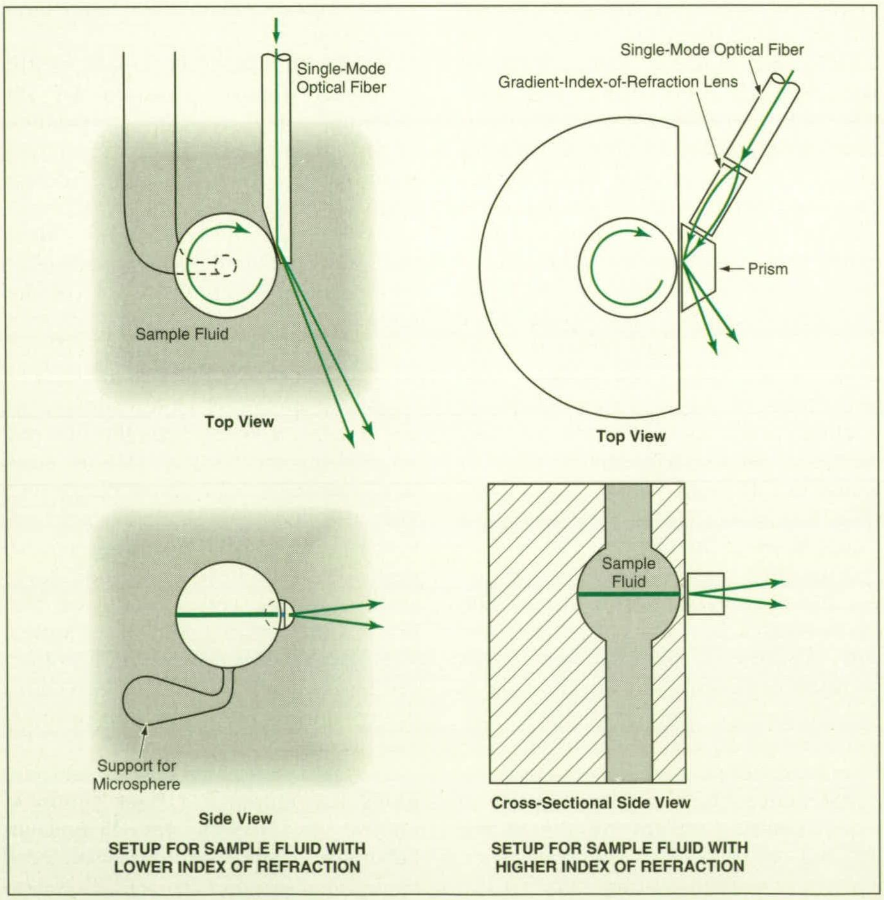
Chemicals of interest could be detected at low concentrations in small samples.

NASA's Jet Propulsion Laboratory, Pasadena, California

Miniature high-resolution optical-absorption sensors for detecting trace amounts of chemical species of interest in gas and liquid samples are undergoing development. The transducer in a sensor of this type is a fiber-optic-coupled optical resonator in the form of a transparent microsphere, (or a microcavity equivalent to a microsphere as described below).

The principle of operation of these sensors is an updated version of that of conventional optical cavity-ringdown spectroscopy (CRDS), wherein resonators in the form of long and bulky Fabry-Perot cavities are used in order to obtain enough effective optical-path length to enable the resolution of small attenuation associated with trace concentrations of analytes. In addition to bulky apparatuses, conventional CRDS requires large samples to fill the Fabry-Perot cavities. In contrast, a microsphere or microcavity sensor of the type under development is designed to be immersed in a sample, which can be small because the microsphere is small. (Alternatively, the sample can be contained in a small cavity as described below.)

The use of transparent microspheres as optical resonators has been reported in a number of prior *Tech Brief* articles. To recapitulate: In a transparent microsphere, resonance is achieved through glancing-incidence total internal reflection in one or more "whispering-gallery" modes, in which light propagates in equatorial planes near the surface, with integer numbers of wavelengths along nominally closed circumferential trajectories. In the absence of external influences, and assuming that the microsphere is made of a low-loss material, the high degree of confinement of light in whispering-gallery modes results in a high resonance quality factor (high Q).



A **Microspherical Optical Resonator** is operated in the presence of a sample fluid that contains an optically absorbing species. The concentration of the species is determined from its effect on the Q of the resonator.

Suppose that the microsphere is illuminated by laser light at its resonance wavelength and is immersed in a sample liquid or gas that (1) has an index of refraction less than that of the microsphere material and (2) contains a highly diluted chemical species of interest that absorbs light at the resonance wavelength. In that case, the Q of the resonator is diminished through absorption by molecules of that species in the evanescent field of the whispering-gallery modes. Because of the smallness of microspheres (typical diameters from tens to hundreds of optical wavelengths), the smallness of the effective volumes of the evanescent fields (typically 10^{-9} cm^3 or less), and the low level of optical losses intrinsic to microspheres themselves, it is possible to detect very small amounts of optically absorbing chemical species through decreases in Q; calculations have shown that in some cases, it should be possible to detect amounts as small as single atoms or molecules.

The left side of the figure depicts a typical setup for a microsphere sensor immersed in a sample fluid that has an index of refraction less than that of the microsphere. If the index of refraction of the sample fluid exceeds that of a material that could be used to construct a microsphere, then one must use a setup like that shown on the right side of the figure: The sample is contained in a microspherical cavity in a capillary cell made from a transparent material that has an index of refraction less than that of the sample fluid. In this setup, the portion of the sample in the microspherical cavity serves as a the whispering-gallery-mode resonator, and coupling between the optical fiber and the microsphere is effected by use of a prism attached to a thin wall that acts as a tunneling (in quantum-mechanical analogy) gap for photons.

The decrease in Q (and thus the amount of the chemical species of interest) can be determined either by measurement of the decrease in the cavity-ringdown time or, if the spectral purity of the laser is adequate, by traditional measurement of transmission bandwidth. Bandwidth measurement is ordinarily used when Q ranges from $\approx 10^5$ to $\approx 10^8$; cavity-ringdown measurement is more convenient for $Q \geq 10^8$ (typically corresponding to ringdown time ≥ 30 ns). While the precision with which the absolute value of Q can be determined is usually no better than a few percent, variations in Q can be measured with greater precision. In state-of-the-art CRDS as performed with Fabry-Perot cavities, it is possible to resolve ringdown times to fractional variations as small as about 2×10^{-3} at data-acquisition rates of about 1 kHz. Hence, it is possible to obtain absorption spectra with satisfactory signal-to-noise ratios even though the losses added by the chemical species of interest may be only small fractions of the intrinsic optical losses of the resonators themselves.

This work was done by Vladimir Iltchenko and Lute Maleki of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*

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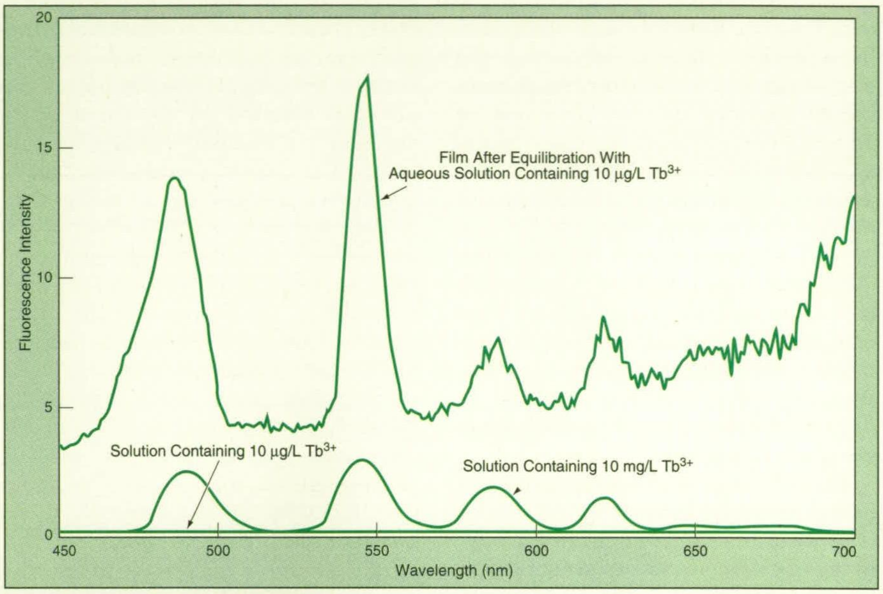
Refer to NPO-21061, volume and number of this NASA Tech Briefs *issue, and the page number.*

Ion-Exchange Films for Luminescence Spectrometry of Rare-Earth Ions

Ions from aqueous solutions are collected in initially transparent films.

John H. Glenn Research Center, Cleveland, Ohio



Fluorescence Spectra of Tb^{3+} Ions were obtained from aqueous solutions and from an ion-exchange film in which ions had been collected from one of the solutions. At a wavelength of 488 nm, for example, the spectral intensity from the film specimen was 4,100 times that from the corresponding solution. The increase in intensity is a result of both increased concentration and the displacement of coordinated water molecules by carboxylate groups of the ion-exchange material.

Thin, initially transparent films made of variants of a polymeric cation-exchange material have been found to be useful for facilitating the luminescence detection and quantitation of several rare-earth ions dissolved in aqueous solutions. A film of this type is prepared in an acid form, then converted to a Ca^{2+} salt form. The acid form of the material consists of polyacrylic acid entangled in a matrix of insolubilized or further cross-linked polyvinyl alcohol. The conversion to the salt form is effected by exposing the film to $Ca(OH)_2$.

The film is placed in an aqueous solution that one seeks to analyze. By virtue of the cation-exchange function of the film material, rare-earth ions from the solution become concentrated in the film. The film is then mounted in a luminescence spectrometer apparatus for analysis of its rare-earth-ion content by fluorometry and/or phosphorimetry. The concentration of the ions in the film increases the fluorometric and/or phosphorimetric response beyond that achievable through spectrophotometric analysis of the solution (see figure), thereby effectively increasing the sensitivity of measurement of concentrations of the dissolved ions.

This approach to spectrometric analysis is denoted generally as solid-phase spectrophotometry (SPS). As practiced heretofore, SPS has involved (1) the use of ion-exchange resins and (2) the enhancement of selectivity and sensitivity by use of chromophoric agents as is done in conventional spectroscopy. Unfortunately, many of the ion-exchange resins used heretofore in SPS are not transparent; on the contrary, they are highly absorbing in the spectral regions of interest and are highly scattering at all wavelengths. In contrast, the present ion-exchange films are sufficiently transparent that they do not interfere appreciably with spectrophotometry throughout the visible and most of the ultraviolet spectrum of interest. Furthermore, because the present ion-exchange material is not particulate and its index of refraction matches that of water, the light-scattering problems associated with prior ion-exchange resins are eliminated.

Another advantage arises in connection with fouling by Ca^{2+} ions: These ions, which are often present in natural waters, compete with the metal ions of interest for sites on ion-exchange resins, thus rendering the resin beads less effective. Because it is in the Ca^{2+} form, the present ion-exchange material resists fouling by Ca^{2+}.

One drawback of the present ion-exchange material is that it emits a large amount of background fluorescence. However, this is not a major drawback, inasmuch as the luminescence from the metal ions of interest lasts much longer than does the luminescence from the film; one can suppress the response to the luminescence from the film by use of instrumentation with a temporal-discrimination capability. The only major drawback is slowness of uptake of ions because of the slowness of diffusion of ions to the ion-exchange material.

This work was done by Kenneth W. Street, Jr., of **Glenn Research Center** *and Stephen P. Tanner of the University of West Florida. For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Materials category.*

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17074.

Coarse Alignment of a Segmented Telescope Mirror

This method provides for correction of large initial alignment errors.

NASA's Jet Propulsion Laboratory, Pasadena, California

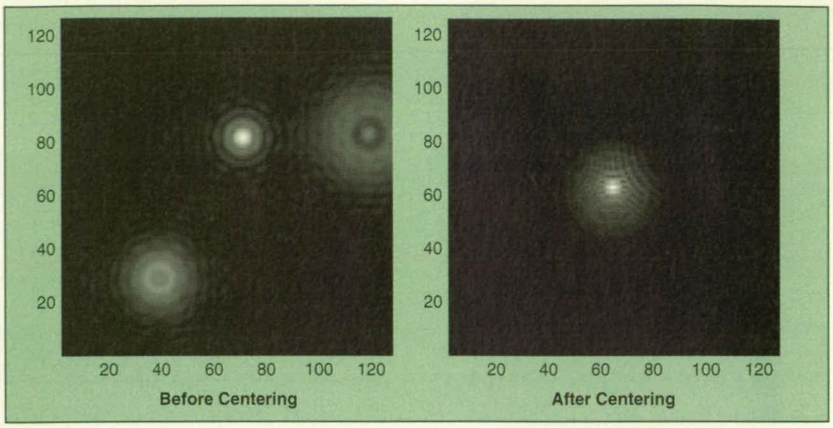
A method of coarse alignment has been proposed for a primary telescope mirror that comprises multiple segments mounted on actuators that can be used to tilt and translate the segments to effect wavefront control in increments as fine as a fraction of a wavelength of light. The method was originally intended for application to the Next Generation Space Telescope (NGST), which will have an aperture about 8 m wide and will include nine primary-mirror segments (a central segment and eight outer segments). The method could also be applied to other lightweight telescopes that are similarly designed to rely on active wavefront-control systems instead of traditional massive structures to ensure high optical quality.

A method of coarse alignment is needed because thermal deformations, mechanical loads, manufacturing errors, and other phenomena can give rise to large initial misalignments of the segments; for example, immediately after deployment, the segments of the NGST could be misaligned by as much as millimeters in piston (displacement along the nominal optical axis) and milliradians in tilt. The present method, to be implemented by the computer that would control the telescope-aiming mechanisms and mirror-segment actuators, provides for reduction of errors in the positions and orientations through the following steps:

1. Aim the telescope at a bright distant point source of light (e.g., a star).
2. Systematically scan the tilts of each mirror segment while repeatedly acquiring star images on an imaging photodetector array at the telescope

focal plane. By an algorithm that involves comparison of images with previous images, those images that initially do not fall on the detector can be brought onto the detector and images formed by all the segments can be centered on the detector (see figure).

3. Temporarily tilt the mirror segments to form separated images on the detector. Operating on each image in turn, vary the piston adjustment of the corresponding mirror segment to concentrate as much light as possible into a smaller focal spot of a given size. Repeat the process with a smaller spot size. After a large focus adjustment, recenter the spots according to step 2. Repeat all of the foregoing until the maximum amount of light is concentrated in the smallest possible focal spot.
4. Form a dispersed-fringe sensor as follows: Insert a grism (a right-angle prism with a transmission grating on the hypotenuse face) into the optical path. Tilt all of the outer segments except one to move their images off the detector and to form a dispersed-fringe image by use of the central mirror segment and the remaining outer mirror segment. Analyze the modulation period and orientation of the fringes to determine the magnitude and sign of the piston error between the two segments. Use this error to perform a coarse-phase piston adjustment of the affected outer mirror segment. Repeat this procedure until all of the outer segments have been adjusted.
5. Perform a somewhat finer coarse phase (image-sharpening) adjustment by use of white-light interferometry: Remove the grism from the optical path, then in a manner similar to that of step 4, use the central mirror segment plus one outer mirror segment at a time to form a white-light image of the star. Adjust the outer segment in piston to obtain the highest peak intensity in the image. Repeat the procedure for the remaining outer segments.



These **Computer-Simulated Pictures** show how images of the same star formed by multiple mirror segments might look in a typical case, before and after centering and before any focus or coarse phase adjustment.

This work was done by Scott Basinger, Andrew Lowman, David Redding, and Fang Shi of Caltech and Chuck Bowers of Goddard Space Flight Center for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category. NPO-20770*

Software for Generating Mosaics of Astronomical Images

It can be run on both single-processor and multiprocessor computers.

NASA's Jet Propulsion Laboratory, Pasadena, California

Software is being developed to "stitch" together multiple astronomical images of small, adjacent patches of the sky into a single mosaic image of a large portion of the sky. These mosaics make data from large areas of the sky readily available for efficient viewing of many types of celestial objects and large-scale structure in the sky that are not apparent on a smaller scale. This software can be run on both single-processor computers and multiprocessor systems. The input patch image data can be of any type, resolution, coordinate system, and projection consistent with the Flexible Image Transport System (FITS), which is a commonly used astronomical data format. The software uses information in FITS headers to reproject the input image data into a common coordinate system and then to translate the data into the output mosaic at a resolution and in a coordinate system specified by the user. This software is part of a "Virtual Observatory" system being developed for analysis and display of astronomical images and catalogs.

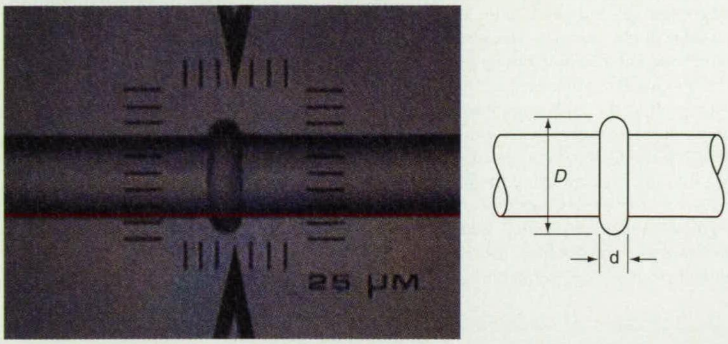
This program was written by Joseph Jacob of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Software category.*

This software is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-21121.

Highly Oblate Microspheroid as an Optical Resonator

Large values of resonance quality factor and finesse have been observed.

NASA's Jet Propulsion Laboratory, Pasadena, California



The **Highly Oblate Spheroidal** portion protruding from the cylindrical portion of this object acts as a high-finesse optical resonator. This object was fabricated by heating a sphere of low-loss silica glass to the softening point and squeezing it between flat cleaved tips of an optical fiber.

Experiments have shown that a highly oblate microspheroid made of low-dielectric-loss silica glass can function as a high-performance optical resonator. The shape of this resonator (see figure) is intermediate between that of (1) microdisk or microring resonators and (2) microsphere resonators, which have been described in a number of previous *NASA Tech Briefs* articles. As described below, the oblate spheroidal shape results in large values of both resonance quality factor (Q) and finesse. Large values of these parameters are favorable for single-mode operation of a laser or an optoelectronic oscillator.

A microsphere resonator exploits the circulation of light by total internal reflection, in "whispering-gallery" (WG) modes characterized by large values of Q. In contrast, the Q values of microring and microdisk resonators are limited because of significant scattering losses on their flat surfaces.

The preferred WG modes of a microsphere resonator are those in which light circulates by propagating along the equator. As a consequence of spherical symmetry, a microsphere resonator is characterized by a large spectral density of modes because, along with the equatorial modes, some modes with small propagation-vector components transverse to the desired equatorial circulation are also coupled to an input/output device. A large spectral density of modes is not favorable for single-mode operation.

The highly oblate microspheroid resonator is not subject to the disadvantages of microsphere, microdisk, or microring resonators. In the highly oblate microspheroid resonator, the greater curvature of the surface in the direction transverse to the desired equatorial circulation effectively decouples the partly transverse modes from the input/output device. As a result, the resonator can be operated in a regime similar to that of single-longitudinal mode Fabry-Perot etalons. The free spectral range (FSR) [the difference in frequency between successive modes] is defined by successive integer numbers of wavelengths packed along the equatorial round-trip light path. For a highly oblate spheroid with an equatorial diameter (corresponding to D in the figure) of the order of hundreds of microns and a typical wavelength of 1.55 µm, an FSR as large as 1 THz is expected; in contrast, for a microsphere of approximately equal parameters, the FSR can be expected to be much smaller (typically between 2 and 10 GHz).

At the same time that it affords a much greater FSR, the highly oblate microspheroid resonator retains the high Q (up to about 10^8) typical of microspheres. This high Q corresponds to a resonance bandwidth of a few megahertz. Consequently, the resonator is characterized by very high finesse (finesse ≡ FSR/resonance bandwidth): typical values of finesse range from 10^4 to 10^5. Heretofore, such high values of finesse were available only in relatively large Fabry-Perot resonators.

If resonators like this one were utilized in simple diode-laser frequency-locking schemes, robust single-mode operation should be possible because the FSRs of the WG modes would be compatible with the gain·bandwidth of typical diode lasers. For spectral-analysis applications, resonators like this one offer a highly attractive combination of miniaturization and unprecedented spectral resolution. For optoelectronic oscillators, resonators of this type could provide convenient sideband frequency references in the terahertz range, provided that appropriate detectors and modulators for this frequency range were also developed.

This work was done by Vladimir Iltchenko, X. Steve Yao, and Lute Maleki of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*

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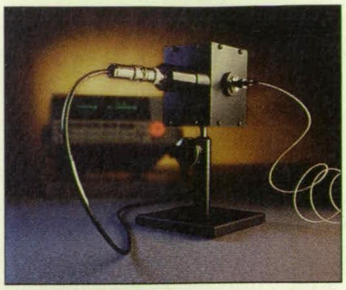
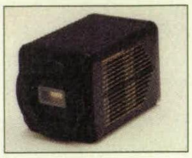


Laser Diode Test System with Integrating Sphere

Keithley Instruments, Cleveland, OH, is making available a custom-designed integrating sphere optical head, to be used with its L-I-V system to test laser diode modules. The Model 2500INT integrating sphere from Labsphere is designed to work with Keithley's Model 2500 photodiode meter, the light intensity measurement instrument in the L-I-V system, facilitating direct optical measurement of laser diode output power. With the Model 2500INT, the L-I-V system becomes a complete single-vendor test solution for measuring the electrical and optical performance of laser diodes, a critical component in dense wavelength division multiplexing. With a diameter of 2 in., the sphere has two ports, three detector choices to cover wavelengths from 500-1700 nm, and two connector choices (SMA and FC). It will be available initially with silicon, germanium, or cooled InGaAs detectors.

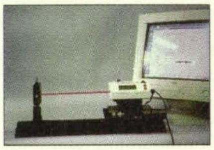
150-A Laser Diode Driver

The PCX-6220 from Directed Energy Inc., Fort Collins, CO, is an air-cooled pulsed current source/laser diode driver designed to drive diode lasers, bars, and arrays. It delivers current pulses variable from 1 A to 150 A, output voltage up to 40 V, pulse widths variable from 50 microseconds to 20 milliseconds, and pulse repetition frequencies variable from single-shot to 5 kHz at duty cycles up to 50 percent. The PCX-6220 provides up to 6 kW peak and 1.2 kW average output power. All necessary power comes from internal DC power supplies, allowing operation on 90-260 VAC 50-60 Hz mains. The driver may be operated through its intuitive front-panel controls.



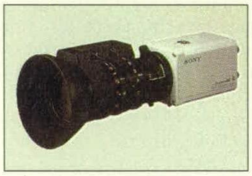
CCD Detector for High-Resolution Spectroscopy

Roper Scientific, Trenton, NJ, has released the Princeton Instruments Spec-10:2K CCD detection system for high-resolution spectroscopy. An addition to the Spec-10™ family, it features a 2048-x-512-pixel format. The company says that its low-noise electronics, as well as deep thermoelectric (-70 degrees) or liquid nitrogen (-120 degrees) cooling, help guarantee the integrity of the acquired data. The 16-bit system can be configured with a front- or a back-illuminated CCD. The device is regulated by an EM-shielded detector controller, and runs under WinSpec, Roper Scientific's 32-bit Windows™ software package. It can be coupled with any Roper Acton Research spectrometer.



Displacement Measuring Interferometer

The DMI™ 500 displacement measuring interferometer from Laser Max, Rochester, NY, is mounted on a flat base to facilitate its mounting or for securing it into position. The company says the unit is based on a differential polarization Michelson interferometer with a simplified detection design. Its measurement beam is directed to a corner cube attached to the object for which linear displacement is to be measured. That beam, returning from the corner cube, reenters the DMI 500, where it is combined with a reference beam. The 1.5-lb. unit's resolution is 0.083 µm and accuracy is 3 ppm with environmental compensation. Its range is 500 mm.



Three-CCD Color Video Camera

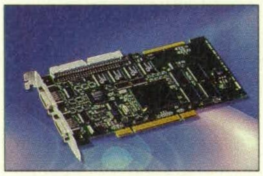
Sony Electronics, Park Ridge, NJ, says its DXC-990 video camera's half-inch 3-CCD sensor incorporates the latest Sony HAD™ technology to provide F.11 at 2000 lux sensitivity with very low smear. The camera features 768 × 494 effective pixels with a horizontal resolution of 850 TV lines and a 63-dB signal-to-noise ratio. The DXC-990 measures 2.76 × 2.83 × 4.84 mm and weighs 1.4 lb. It can be controlled through the unit's side panel, with an RM-C950 remote control unit, or by using an external computer via an RS-232C interface. The camera accepts 38-mm bayonet mount lenses and can be fitted with an optional microscope coupler.

Double Monochromators

The double monochromators from McPherson Inc., Chelmsford, MA, are configured by joining two individual instruments into either additive- or subtractive-dispersion double spectrometers. These devices feature dual 350-mm focal lengths with f/4.8 (±0.07-nm) accuracy in the visible, reproducibility of ±0.005 nm, and continuous stray-light rejection of 10^{-9} to 10^{-10}. The double additive monochromator includes mechanical linkage of two sine drives and wavelength control via a single-motor high-resolution scan drive. Subtractive units may use single or dual motor drives, depending on their configuration. Stepper drives are interfaced for operation via PCs.

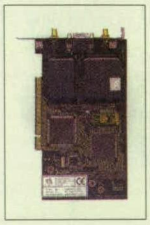
Sampling Accessories for Near-IR Analyzer

Analytical Spectral Devices, Boulder, CO, introduces sampling accessories for its LabSpec® Pro near-infrared analyzer. They include a high-intensity source probe, a high-intensity contact probe, and a multipurpose fiber optic fixture. The source probe is designed for measuring solids, pastes, powders, and granular materials. The contact probe is intended for analysis of raw materials. The fiber optic fixture was developed for fluid analysis. Featuring a fiber optic input, the LabSpec Pro has a wavelength range from 350 nm to 2500 nm. Scanning time is 0.1 second and sampling interval 2 nm.



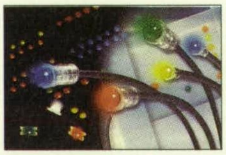
Frame Grabber

Matrox Imaging, Dorval, Quebec, Canada, says that its Meteor-II Camera Link™ frame grabber was developed in response to Camera Link™, the new high-speed digital serial link for vision applications. Camera Link is built on Channel Link™, an LVDS-based high-speed serial transmission technology. from National Semiconductor.® It delivers transmission rates up to 2.38 Gbps over distances of up to 10 meters. The Meteor-II Camera Link supports one, two, or four tap monochrome, as well as component RGB, area or line-scan video sources.



Single-Photon-Counting PC Board

PicoQuant GmbH, Berlin, Germany, offers the TimeHarp 200 PC board, which it calls a low-cost fully integrated system for time-correlated single-photon counting on a single PC card. The board has 40-ps channel resolution, and continuous count rates of greater than 2 million counts per second. The new board is designed for the PCI bus and the company says makes full use of bus-mastering DMA to permit continuous data acquisition. PicoQuant says that the board is suitable for fluorescence lifetime investigations with the company's PDL 800 as the excitation source. The input triggers are programmable for various input signals.



Flexible Light Pipe

Bivar Optoelectronics, Irvine, CA, introduces the FLP 5 Series flexible light pipe. The company says the series' enhanced brightness is achieved with a new round 7-mm lens size, 4 mm larger than the previously available size, enabling a wider viewing area and greater contrast ratio. The new series incorporates all of the features of Bivar's original light pipe series, including the company's patent-pending bonding technology that creates a monolithic structure of lens and plastic optical fiber. The series is offered in a wide selection of lens shapes, sizes, and colors, including red, green, blue, yellow, amber, turquoise, and high efficiency red, and in either through-hole or surface-mount configurations.

Large-Field Carbon Dioxide Laser Platform

Universal Laser Systems, Scottsdale, AZ, says that its X2-SuperSpeed™ is the world's fastest carbon dioxide laser platform. Two laser beams work together for simultaneous multiline engraving. The instrument offers a 812-x-457-mm work area, and is part of Universal's "Integrated Family of Laser Products" that is cross-platform compatible with the company's Quick Change Laser Cartridges™. Universal says the multibeam technology can provide up to a 500-percent increase in productivity on certain applications and with certain laser configurations.

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03 ❑ Computers/Peripherals
04 ❑ Software
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34 ❑ Power supplies & batteries
35 ❑ PCs & laptops
06 ❑ Workstations
36 ❑ EDA/CAE software
37 ❑ CAD/CAM software
17 ❑ Imaging/video/cameras
38 ❑ Lasers & laser systems
39 ❑ Optics/optical components
40 ❑ Fiber optics
41 ❑ Optical design software
20 ❑ Motion control/positioning equipment
30 ❑ Fluid power and fluid handling devices
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13 ❑ Metals
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Commercialization Opportunities

High-Speed Image Compression via Optical Transformation

A proposed solution to compression of image data at high throughput rates relies on a purely optical means of Fourier transformation. This approach reduces the computational and power requirements imposed by such systems.
(See page 34.)

Micromachined Broad Band Light Sources

These light sources operating at temperatures exceeding 2,500 K generate highly bright white light. Potential applications are in spectroscopic instruments and in automobile dashboard displays.
(See page 44.)

CMOS Image Sensors Capable of Time-Delayed Integration

Use of CMOS imagers instead of CCDs reduces power requirements and allows integration of control electronics and signal processing on-chip, which results in highly compact complete imaging systems, including even analog-to-digital conversion on-chip.
(See page 47.)

Ceramic Ribbons as Waveguides at Millimeter Wavelengths

Suitably designed ribbons made of alumina can serve as low-loss dielectric waveguides at frequencies from 30 to 300 GHz. The achievable attenuation factor is 10 dB/km.
(See page 49.)

"Smart Coatings" for In Situ Monitoring of Engine Components

New films are being developed to enable monitoring of aircraft engines during flight and inspection. Such coatings deposited on turbine and compressor blades, turbine blade hubs, and other critical parts can detect incipient failures and other adverse phenomena.
(See page 54.)

Improvements in Electroformed Copper Alloys

Some successes reported in this area include copper and copper alloys having mechanical properties competitive with those of electrodeposited nickel; production of low-additive, nonalloyed electrolytic copper deposits with resistance to recrystallization; and codeposition of fullerenes to form a dispersion alloy of superior strength with no loss of thermal conductivity.
(See page 56.)

Tooling for Controlled Grinding of an Edge To Remove Defects

A special-purpose grinding tool and fixtures developed for rocket-engine applications speed up the grinding process by a factor of 10.
(See page 60.)

Biomorphic Gliders

These are small robotic microflyers that embody some key features of bird and insect flight. A large number of these microflyers can be released from aircraft or spacecraft to explore and gather data on the surrounding environment.
(See page 65.)

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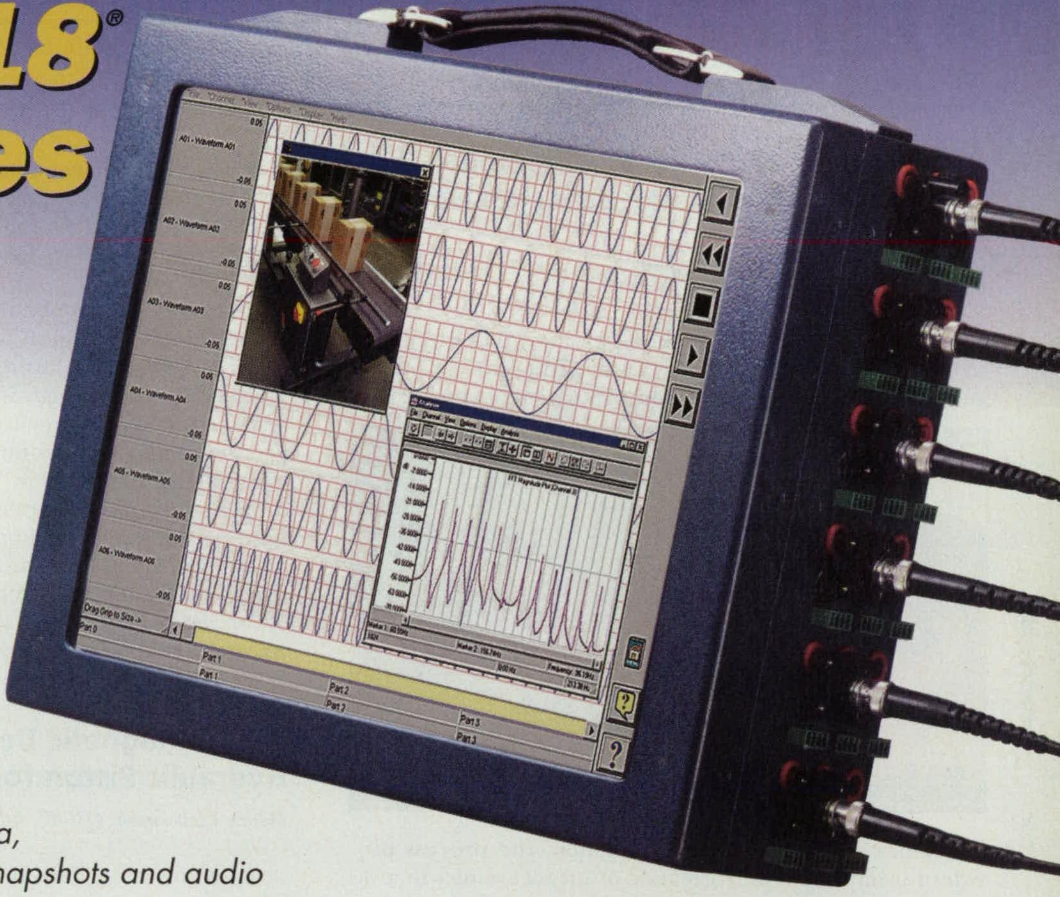

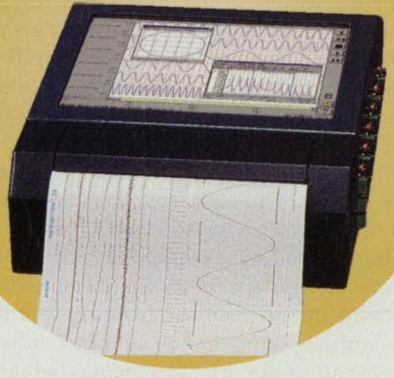

Technologies of the Month

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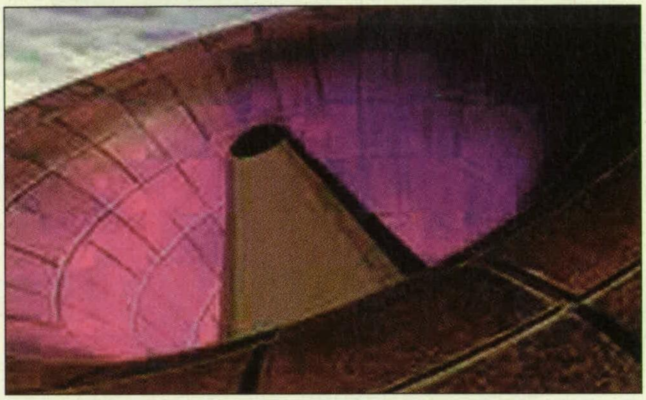
Nano-Fiber-In-Nano-Pore Technology Enhances Electrical Characteristics of Piezoceramics

Andrea Mica, IntelliKraft

A new manufacturing technology modifies the nanostructure of materials, from semiconductors to metals and dielectrics, enhancing their electro-mechanical characteristics and reliability. In particular, the process provides for improved performance of piezoceramics in a variety of applications.



Under the trade name IntelliKraft™, this new, enhanced piezoceramic offers size and power advantages for ignition systems, electrostatics, and power generation devices. The material's uniqueness stems from a patented technology called "nano-fiber-in-nano-pore," which changes the piezoceramic's microstructure to create a greatly improved piezoelectric effect and higher mechanical strength over traditional piezoceramics. The metallic nano-fibers can be used to improve the characteristics of a number of materials, but the process offers the greatest advantages in piezoceramics; that is, a material that converts motion (for example, vibrations caused by an introduced frequency) into electricity.

One of the most promising uses is an ignition system in automobiles, boilers, and furnaces. Compared with traditional coil ignition systems, a piezoceramic system offers optimal combustion enabled by a sequential series of ignition pulses rather than a single spark. It also offers reduced emissions and increased power resulting from more efficient combustion, less ignition equipment (no distributor, ignition coil, high voltage cables) for greater system reliability, and reduced electromagnetic interference (EMI).

The enhanced electrical characteristics of the IntelliKraft piezoceramic technology enable it to be used as a high-voltage transformer charging a high-voltage capacitor to deliver a single spark; as a high-voltage igniter delivering a series of high-voltage sparks in a frequency range from 0.1 Hz to 100 kHz; and as a high-voltage discharger, providing a stable and continuous discharge across a gap.

Piezoceramic elements are resistant to vibration and the effects of fuel, solvents, antifreeze, oil, and other chemicals. The ability to provide a continuous discharge enables the use of otherwise difficult-to-ignite fuel/air mixtures (for example, water/fuel emulsions containing a high percentage of water).

Other potential applications include use as a piezo transformer in electrosurgical and electrostatic systems. Piezoceramic electrosurgical instruments are capable of delivering precisely controlled high voltage for micron-level tissue cauterization to minimize collateral damage and provide the surgeon with maximum control. Piezoceramics, when used in high-voltage electrostatic sprayers, create extremely fine droplets for uniform coverage and increased surface adhesion. Enhanced piezoceramics are ideal for any mass-produced high-voltage system, including electro-optical systems, signal equipment, capacitors, and their chargers.

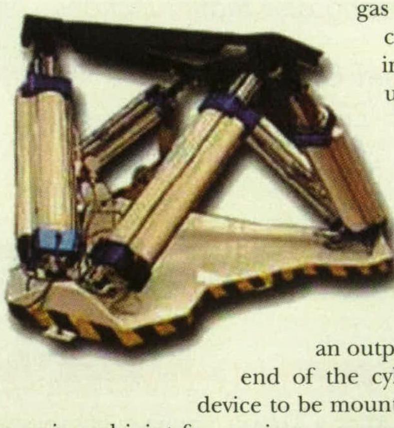
Get the complete report on this technology at: ***http://www.nasatech.com/techsearch/tow/intellikraft.html***

Electromagnetic Device Surpasses Hydraulic Piston for Controlling Motion

Henry Lieberman, Q3000, Advanced Motion Technologies

Since the late 1700s, the venerable hydraulic piston has been the mainstay for controlling mechanical motion. However, hydraulics have numerous drawbacks: they are relatively clumsy, leak pollutants, require frequent maintenance, and are energy inefficient and susceptible to corrosion.

A completely new type of electric linear motor is more precise, energy efficient, extremely powerful, and easier to maintain than the hydraulic piston. Called an electromagnetic actuator, this device features a single moving part that is capable of thrusts between 2.2 pounds (1kg) and 100 tons. The patented technology uses a magnet array mounted on a piston/armature that moves on simple slide bearing rings inside a coil array cylinder. The armature is sealed, creating a pneumatic piston with an internal gas spring reservoir that can be tuned for maximum efficiency and used to counteract motion caused by the dead weight of any device to which it is attached. Unlike a piston, the electromagnetic actuator features an output shaft through one end of the cylinder, enabling the device to be mounted by the other end to a universal joint for maximum movement in virtually any



direction. And because everything is internal, the entire device can be fully sealed, capable of operating in sterile and harsh environments. Unlike hydraulic pistons, this actuator is silent and extremely smooth, making it ideal for closed areas and an almost unlimited number of applications.

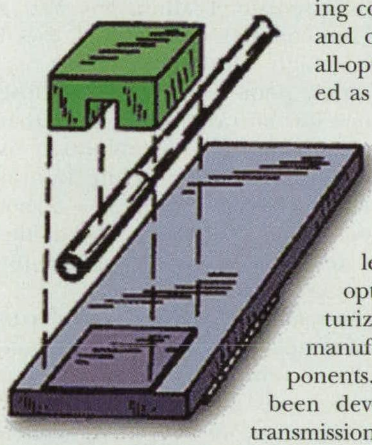
The remarkable precision, strength, and flexibility of this technology make it perfect for a wide range of uses, including training simulators, precision manufacturing (robotics, pick-and-place operations), automotive (suspension, steering, stabilization), marine steering and jet aircraft launching, flying shears in industry, elevator closures, weight-bearing motion (entry opening and shock absorbing systems), and periscopes.

Get the complete report on this technology at: ***http://www.nasatech.com/techsearch/tow/q3000.html***

New Method Improves Optical Fiber Attachment to Substrates

Ed Ohlmann, Tektronix, Inc.

The Holy Grail for telecommunications companies today is something called the all-optical network. Constructed entirely of fiber-optic pathways — from long distance underground cables, to local area networks, metropolitan networks, and building networks, to patch cords and cable assemblies connecting computers, servers, routers, and other components — the all-optical network is being touted as the solution to the massive bandwidth crunch caused by Internet traffic and other data transmission demands.



One of the major challenges to getting to the all-optical network is the miniaturization and high-volume manufacture of fiber-based components. Tiny laser diodes have been developed to facilitate the transmission of optical signals. Other devices called wave division multiplexers aid optical transmissions by splitting light into multiple frequencies, each capable of carrying thousands of voice signals and hundreds of data transmissions in a single fiber-optic cable. But getting all these fibers to line up so that the beams of light travel without a hitch is exceedingly difficult, and the smaller the fiber, the tougher it is to make the interconnection.

Traditionally, fibers have been attached to the structure that holds the laser light source to the circuit board using a metal coating that solders the fiber to the laser structure, but this method often caused the fiber's position to shift, causing misalignment. Other commonly used methods involve placing the fiber in a small metal tube to avoid the direct soldering problem, and soldering the fiber to the substrate with either metal or a glass composition.

This technology introduces a new method for securing optical fibers to substrates, signaling an important breakthrough in board-level optical solutions. Developed by Tektronix, Inc., this new method creates a structurally sound connection between an optical fiber and a substrate using a silicon/gold eutectic alloy.

This new method starts with a conventional external gold coating on the optical fiber. But instead of using a metal solder to attach the fiber to a substrate, a silicon-retaining member with a fiber-retaining groove in it is placed, with the fiber in it, onto a gold-coated metal pad deposited onto an alumina substrate. Heated to approximately 370°C using a resistor attached to the underside of the substrate, the silicon and gold form an alloy that securely adheres the fiber to the metal pad. The advantages of this method include more precise alignment of the fiber with the light source because the physical manipulation of the fiber is kept to a minimum, and stress-related problems caused by solder-related temperature differentials between the fiber and substrate are avoided. Applications for optical interconnects using this technology include high-speed data and telecommunications, portable diagnostics, and digital signal transmission in severe environments, including shipboard communications, transportation, test and measurement, and avionics.

Get the complete report on this technology at: ***http://www.nasatech.com/techsearch/tow/tektronix.html***

Thermoplastic Elastomer Intumescent Fire Shield

Richard Marczeski, Licensing Manager, Delphi Automotive Systems

Delphi Automotive Systems is a world leader in automotive components and systems technology. Delphi currently has thousands of patents in its portfolio and generates hundreds more each year on a wide variety of technologies. Recognizing the value of its impressive portfolio of product and process technologies, Delphi created Delphi Technologies, a subsidiary exclusively dedicated to creating, managing, protecting, and leveraging Delphi's intellectual property.

This material can help prevent a fire from spreading. It is lightweight, chemically resistant, sound-deadening, can employ recycled materials, and retains mechanical strength integrity in the event of a fire. The material also has design flexibility to meet specific application requirements. When it is exposed to fire, it foams and chars to form a barrier, which delays the spread of the fire and reduces the flow of heat. Although made of a plastic/rubber blend, the material does not melt, drip, or burn through even after long exposure to intense fires.

The intumescent material has been tested in vehicles exposed to large-scale, fuel-fed fires. The material can be used in residential or industrial buildings in order to contain fires, slow down flame spread, and protect structural beams from softening by exposure to high temperatures. The versatility of the material makes it ideal for industries such as aerospace, manufacturing, transportation, and even home appliances.

Get the complete report on this technology at: ***http://www.nasatech.com/techsearch/tow/delphi.html***

What to Know Before Switching to Digital Video

New digital camcorders and DVD players are now common in the consumer market. Industrial video users are now evaluating a move to solid-state or hard disk digital video recorders to replace the current generation of Hi-8mm videotape recorders. The primary reasons given for this desired change are:

- Elimination of videotape
- Improved reliability
- Reduced maintenance requirements and costs
- "Digital video is better"

However, the other operational requirements outlined in the early 1990s still remain — namely, minimum two-hour recording, multiple video source recording, improved video quality/resolution, and reduced maintenance, operating, and life-cycle costs.

Digital video is very different from analog tape video recording, and there are a number of critical issues that anyone considering changing to digital video should understand in order to make an informed decision.

When asked why they wanted to switch to digital solid-state video recording, many users stated that "digital video is better." That is not exactly true, and is a common misconception. Traditional analog video is recorded using 30 separate video frames each second (RS-170 Standard), with each frame containing equal full-resolution video. Digital video, however, uses a different process utilizing different digital data rates for each frame of video that dramatically can alter the quality of the video image in different frames. Pure digital video requires very high digital bit rates — typically 125-250 Megabits/second — which, in turn, requires massive amounts of expensive solid-state or hard disk memory.

In order to reduce the memory requirements for digital video, a variety of "compression" techniques were developed to reduce the amount of required data. These compression techniques use motion prediction algorithms that dramatically can reduce the amount of solid-state memory required. This is accomplished by looking at scenes that have little or no motion, or non-complex scenes (such as looking at primarily blue sky), and eliminating data and using previous data for that time. Also, in cases of non-complex scenes or scenes with little or no motion, the data bit rate can be reduced without dramatic reduction in video quality. However, for complex scenes or scenes with high motion, high bit rates and very little compression must be used to achieve acceptable quality video.

TEAC's MDR-80 data recorders perform data loading and image transceiver functions, as well as recording digital data, and analog or digital video.

The MPEG Standard

The current digital video compression standard is MPEG-2, which can run using data bit rates from approximately 0.67 Mbits/sec. up to 25 Mbits/sec. (MPEG refers to the Moving Pictures Experts Group, which sets standards for compressing and storing video, audio, and animation in digital form.) The higher the bit rate, the higher the video quality. Unfortunately, higher bit rates also require more memory storage, and solid-state memory is expensive. In an attempt to reduce the solid-state memory requirement, most digital video recorders try to use the lowest bit rate possible that will provide the video quality required. Reducing the bit rate too much results in inferior, low-quality video, even though it is still digital. In this case, digital video is definitely not better.

How do these bit rates actually translate into different observable levels of video quality? As stated above, a demonstration of MPEG video using simple, non-complex scenes, or scenes with little or no motion, can look good at lower bit rates. But using those same bit rates to record a complex scene or a scene with lots of motion will look very poor. As such, the user must be careful to analyze the video under conditions that reflect the expected use. For example, a demonstration of recorded digital MPEG video of mostly blue sky with very little changing scene or motion can look good at lower bit rates of 2 Mbits/sec. to 4 Mbits/sec. Yet, a highly complex scene at high speed with high motion will look extremely poor if recorded at those same low bit rates. Remember that motion and scene complexity is measured not only by the rate at which the scene changes — a simple puddle in the rain is one of the most demanding scenes possible for the compression algorithm.

At the same time, it may be possible to record simple displays, such as some radar and vehicle system displays, at lower data rates down to approximately 2 Mbits/sec. before image degradation becomes noticeable. But recording these types of displays at 1 Mbit/sec. or lower generally results in unusable video quality where the information is not readable, especially if detailed information is presented on the display.

Solid-State Memory Requirements

The amount of solid-state memory required for digital video recording is directly related to the data rate used by the MPEG compression algorithm. The memory requirement for one hour of recording can be easily calculated by multiplying the data rate per second x 60 seconds x 60 minutes. For example, to achieve Hi-8mm video quality for

normal replay requires a minimum 8Mbits/sec. data rate, which yields 3.6 Gbytes of memory for one channel for one hour of recording, or 7.2 Gbytes for two hours. This requirement jumps to 10.8 Gbytes if you wish to achieve full Hi-8mm quality for normal play and still frame.

Unfortunately, solid-state memory still is expensive, and even though prices have been reduced significantly in past years, the past 18 months have seen a leveling out of the curve. Currently, solid-state memory costs approximately $2,000 per Gbyte. As such, there is a strong desire to reduce the amount of solid-state memory used in a digital video recorder in order to reduce cost and size.

The result is that many digital recorder products currently offered on the market state that they use MPEG-2 compression. They feature low data rates to justify reduced solid-state memory requirements, or do not identify the data rate and just utilize a small amount of memory to reduce the cost.

Reliability and reduced maintenance requirements are distinct benefits of a solid-state recorder. However, one must also consider operating and total life cycle costs (acquisition costs + maintenance and logistics costs), including the cost of support recording media (solid-state memory) and ground playback equipment.

Current Hi-8mm video recorders use standard commercial Hi-8mm videocassettes at a cost of less than $10 each. High-quality Hi-8mm recorders typically will require a new videotape approximately once every six months, or two tapes per year, for a total annual media cost per recorder of only $20 per deck.

In contrast, current solid-state memory costs approximately $2,000 per Gbyte. As detailed above, it requires 7.2 GB of solid-state memory to achieve full Hi-8mm video quality for two hours. This amount of raw memory alone currently costs at least $14,500. Including packaging costs, this size solid-state memory module will cost approximately $17,500, compared to only $10 for a Hi-8mm tape.

One of the key benefits associated with solid-state recording is the projected improvement in reliability over tape-based recorders. Current tape-based recorders achieve 2,000 hours mean time between failures, while their solid-state counterparts offer 10-12,000 hours. The added reliability may mean the difference between a successful recording and a failure.

Digital offers some excellent potential for applications when done correctly. The costs associated with the transition go well beyond comparing the price of a blank DVD and a blank tape. Digital is here, and while the cost of entry is high, the benefits are improved reliability, reduced maintenance, and flexible use of the digital results.

For more information, contact the authors of this article, Dave Husted, Senior Vice President and Industrial Products Div. Manager; and Ron Burnett, Marketing Manager, TEAC America, Montebello, CA; Tel: 323-727-4866; www.teac-recorders.com.

Special Coverage: Imaging/Video/Display Technology

High-Speed Image Compression via Optical Transformation

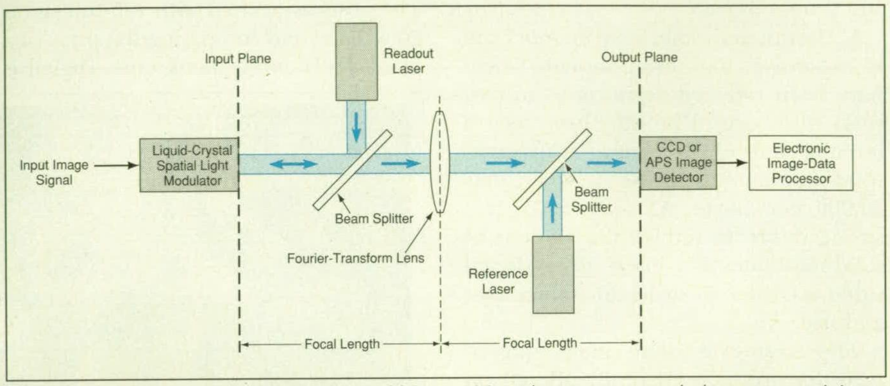
A lens would be utilized as an optical Fourier transformer.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed method of compressing image data would exploit the well-known capability of a converging lens to generate the Fourier transform of an image by purely optical means, in much less time than is needed to compute the discrete Fourier transform of a sampled image by use of digital electronic circuits. Inasmuch as a transform (whether of the Fourier, discrete-cosine, or other type) is the most computation-intensive part of almost any electronic image-compression scheme, the speedup afforded by the proposed method could make the difference between success or failure in applications in which there are requirements to compress image data at high throughput rates. In addition, because high-speed digital image-processing circuits are typically power-hungry, the use of optical Fourier transformation can reduce power consumption.

The Fourier-transform property of a converging lens can be summarized as follows: When the lens is placed at its focal distance from both an input and an output plane, then the image formed by the lens on the output plane is a Fourier transform of the object or image at the input plane. The two-dimensional spatial-frequency vector associated with any given point in the output image is proportional to the position vector from the optical axis to that point.

In the proposed method (see figure) the input image would be generated on a liquid-crystal spatial light modulator illuminated with a readout laser, which would be coherent with a reference laser. (It would be necessary to generate the input image in this way because the coherence of the laser light would be needed to form a hologram described subsequently.) A lens would be located at its focal distance from the input plane as well as from the output plane, where a charge-coupled-device (CCD) or an active-pixel sensor (APS) would be placed to detect the image. As a result, the Fourier transform of the input image would be formed on the image detector.



The **Lens, Lasers, and Beam Splitters** would be positioned to generate a hologram containing a Fourier transform of the input image. The optical propagation time to form the hologram would be much shorter than the time needed for digital electronic computation of the Fourier transform.

Capturing the intensity magnitude at the detector is not sufficient for reconstructing the image. For this reason, it would be necessary to write a hologram onto the image detector by means of interference between the lens-transformed image beam and the reference laser beam.

Because most of the information in a typical image is concentrated at low spatial frequencies, the bulk of information in optical Fourier transform would be concentrated about the optical axis. The image detector would sample the Fourier transform. The samples would be digitized, then entropy-coded by use of established digital electronic techniques

This work was done by Deborah Jackson of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*

NPO-20638

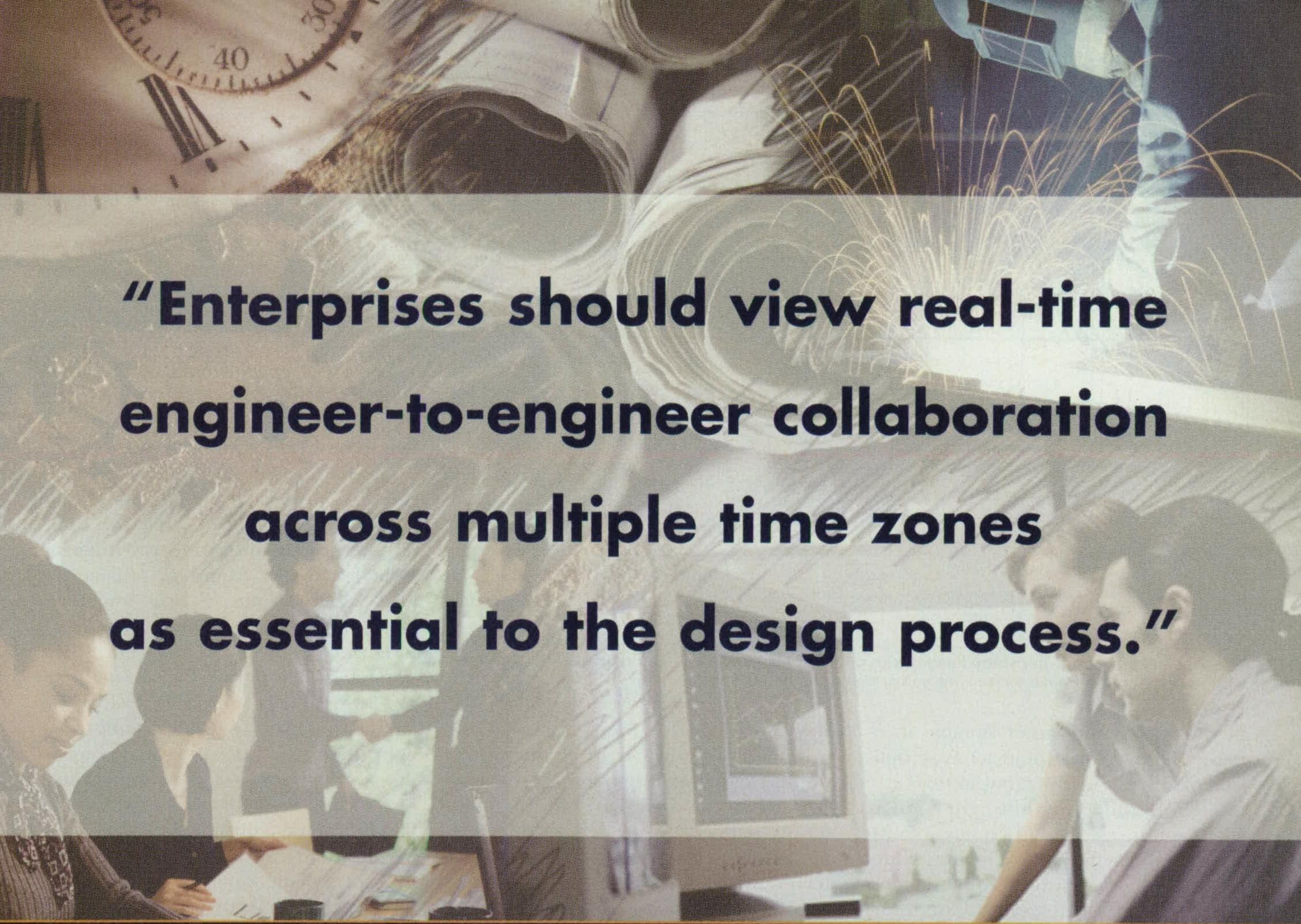
High-Speed Optical Image Compression at Lower Power

White-light holography would enable elimination of a power-hungry spatial light modulator.

NASA's Jet Propulsion Laboratory, Pasadena, California

In an alternative to the optical image-compression method of the preceding article, the Fourier transform of the input image would be formed on the output plane by white-light holography, instead of by laser holography. The principal advantage of the alternative method would be decreased power consumption: A state-of-the-art liquid-crystal spatial light modulator needed to implement the method of the preceding article consumes about 10 W of operating power, and the liquid crystals must be maintained at a temperature near 25 °C. On the other hand, an image detector of the active-pixel-sensor (APS) type, needed to acquire the Fourier-transform image in both the method of the preceding article and in the alternative method, consumes only about 50 mW. Because the spatial light modulator would not be needed in the alternative method, the power consumption of the image-compression system could be greatly reduced.

In the alternative method (see figure), the input image could be formed



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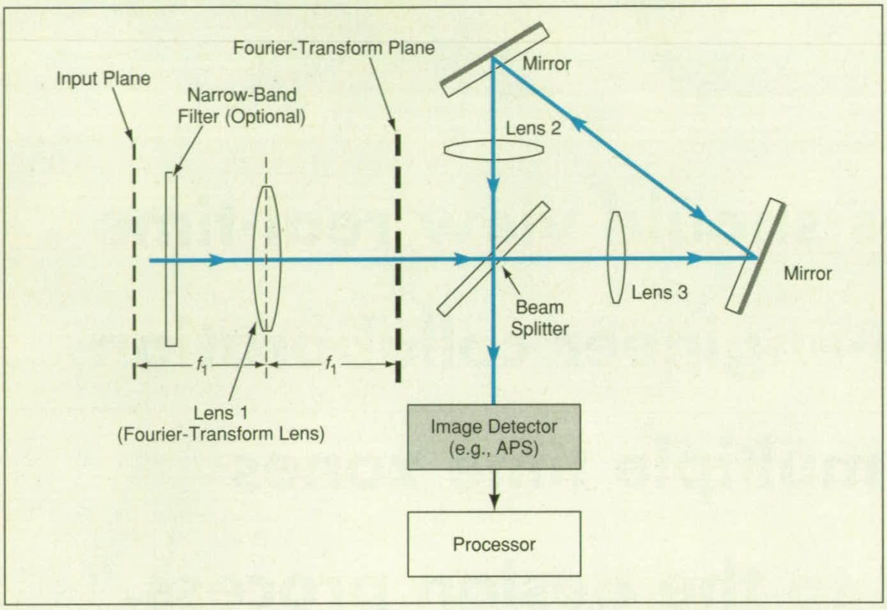


Two White-Light Fourier-Transform Images with different magnifications would be made to interfere with each other to obtain a white light hologram on the detector plane.

in sunlight or any other suitable incoherent light. A lens would act as an optical Fourier transformer, but in this case, two slightly different white-light Fourier-transform images would be made to interfere with each other to form a white-light hologram. An interferometric loop would extract the relevant phase information. The particular configuration of the interferometric loop, originally developed for white-light holography, would simultaneously optimize the spatial and temporal overlap of the input intensity pattern, as needed to obtain a measurable contrast for white-light interference. Different magnifications would be used along the clockwise and counterclockwise circuits of the interferometer, in order to make each point in the image interfere with itself; this design would eliminate the need for a spatial light modulator and lasers to obtain the coherence needed to generate a hologram. The design problem then becomes one of matching the contrast ratio of the white-light hologram with the dynamic range and offset of the image detector.

The input image would be presented at the left focal plane of the Fourier-transform lens, which would have a focal length f_1. The Fourier-transform image would be formed at a distance f_1 to the right of this lens, at the entrance to the interferometric loop. Within the interferometric loop, two lenses with differing focal lengths of f_2 and f_3, respectively, would refocus the Fourier-transform image onto the image detector at two different magnifications. The magnification of the clockwise circuit would be f_3/f_2, while that of the counterclockwise circuit would be f_2/f_3. Components of the light that came from the same point in the Fourier-transform plane would interfere on the detector plane and thereby provide phase information. Light coming from different points in the Fourier-transform plane would be superimposed incoherently on the detector plane. As in the method of the preceding article, the low-spatial-frequency image information would be concentrated about the optical axis on the detector plane.

The major drawback of white-light holography is that the coherently interfering waves comprise only a small fraction of the total light, so that interferograms are unavoidably superimposed on bright backgrounds. The use of an electronic (as opposed to a photographic-film) image detector would make it possible to process the image information electronically to remove the bright background. Implementation would involve a formidable challenge in that it has been estimated that 50 dB of dynamic range would be needed to eliminate the background signal while an additional 30 dB of dynamic range would be needed to achieve 10-bit precision in pixel readouts. One could use a narrow-band filter to reduce the brightness of the background light and increase the coherence length of the light to obtain more margin for design specifications.

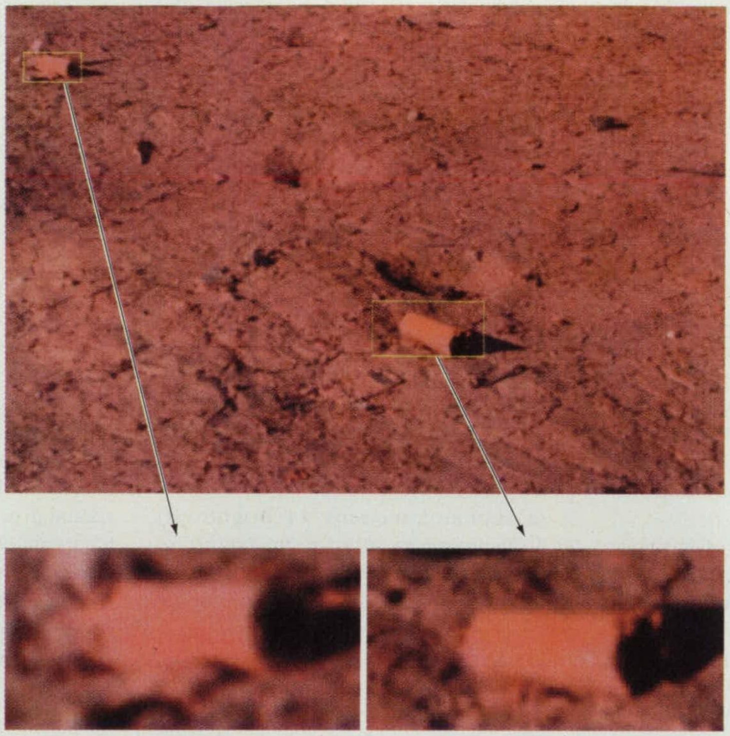
This work was done by Deborah Jackson of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*
NPO-20639

Algorithms for Recognition of Objects in Color Stereo Images

Objects of known size, shape, and color can be recognized in real time.

NASA's Jet Propulsion Laboratory, Pasadena, California

Algorithms have been developed to enable a robotic vision system to recognize, in real time (at a rate between 0.5 and 2 frames per second), known objects lying on the ground. In the original intended application, the algorithms would be executed by off-the-shelf computer hardware aboard a robotic vehicle that would traverse military ordnance-testing ranges to search for unexploded bombs. A stereoscopic pair of color video cameras aboard the vehicle would acquire images of the terrain near the vehicle, and the algorithms would process the digitized images to recognize the bombs by their known size, shape, and color. The algorithms may also be adaptable to other, similar robotic-vision applications — for example, automated recognition of color traffic signs for alerting drivers in automobiles.



Candidate Objects are identified in an image, then resampled to a canonical size and orientation for further processing.

The methodology implemented by the algorithms can be summarized as follows: First, raw data from a pair of color stereoscopic images are subjected to rapid preliminary processing to detect candidate locations (that is, locations to be examined more thoroughly for the presence of bombs). Once the candidates have been detected, additional computations are performed to reduce false alarms, reason about the remaining available image data, and make a final decision about each candidate.

The preliminary processing includes several steps that result in the generation of range data from the disparity between the left and right images of the stereoscopic pair. The stereoscopic range data are used initially, along with other abstracted data, to place bounds on the sizes of objects in the scene; this makes it possible to eliminate, from further consideration, all parts of the scene that do not contain candidate objects within the size range of the objects of interest (the bombs in the original application). This elimination reduces the search space and reduces the incidence of false alarms.

Next, the color of each pixel in the remaining search space is quantified by computing a unit vector in a three-axis color space from its red, green, and blue brightnesses. Each pixel is then classified as either like or unlike an object of interest, depending on whether its unit color vector does or does not lie within that volume in the color space that represents the range of anticipated variation of color of the object of interest, given anticipated variations in lighting, viewing angles, and natural discoloration from weathering. Candidates are identified by locating blocks of contiguous pixels that have been so classified.

After detecting candidate locations, a variety of verification software modules can be applied to reduce false alarms. Although verification is more computation-intensive than are the preceding steps, the verification process does not greatly increase the overall computation time because much of the image has been eliminated from consideration in the preceding steps.

The first step in the verification process is to compute the dominant orientation of the object at each candidate location, then use the resulting information, along with the range data, to resample the candidate object at a canonical scale and orientation (see figure). Each resampled candidate object is then subjected to a series of tests that rate the spatial distribution of color, the likelihood that edges consistent with those of the objects of interest are present, the height of the candidate object, and the contrast between the object and the background. Weighted sums of the quantitative results of these tests are used to compute the probability that the candidate object is one of the objects of interest; the candidate is deemed to be an object of interest if the computed probability exceeds a predetermined threshold value.

The algorithms were tested on 350 images acquired at a live-fire test range near Nellis Air Force base. (Training for the candidate-detection stages was performed on a set of images collected at the same site one year earlier.) Overall, 324 instances of 75 different bombs of the same type appear in the test set. Each bomb was detected in at least one of the images that showed it. Several false negatives occurred in instances in which the bombs lay at significant distances from the cameras and thus yielded small images. In these cases, the bombs were always detected when the cameras traveled closer to them. In addition, 19 false alarms were detected. Of the candidate objects reported, 92.6 percent were found to be bombs.

This work was done by Clark F. Olson of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Information Sciences category.*
NPO-20754

A Metric for Visual Quality of Digital Video

This metric is based partly on human visual processing and is computationally efficient.

Ames Research Center, Moffett Field, California

DVQ (which stands for "digital video quality") is a metric for evaluating the visual quality of digitized video images. Other video-quality metrics have been proposed, but it appears that each of them (1) may be based on mathematical models that are not related closely enough to the characteristics of human perception, in which case it may not measure visual quality accurately; or (2) may entail such large amounts of memory or computation that the contexts in which it can be applied are restricted. In contrast, DVQ was developed in an effort to incorporate mathematical models of human visual processing while maintaining computational efficiency so that accurate metrics can be computed in real time by use of modest computational resources.

DVQ incorporates aspects of early visual processing, including dynamic adaptation to changing brightness, luminance and chromatic channels, spatial and temporal filtering, spatial-frequency channels, dynamic contrast masking, and summation of probabilities. Among the most complex and time-consuming elements of other proposed metrics are spatial-filtering operations that implement multiple-band-pass spatial filters characteristic of human vision. In DVQ, spatial filtering is accelerated by use of the discrete cosine transform (DCT); this provision affords a powerful advantage because efficient computational hardware and software for the DCT are available and because in many potential applications, DCTs may have already been generated in image-data-compression processing.

DVQ is defined by, and computed in, the process illustrated in the figure. The input to the process is a pair of color video image sequences, of which one is denoted the reference sequence and the other is denoted the test sequence. The first step of the process consists of various sampling, cropping, and color transformations that serve to restrict processing to a region of interest and to represent colors in the sequences in a perceptual color space [e.g., in terms of L (a standard measure of brightness) and chromaticity coordinates (standard measures of hue and saturation) specified by the Commission Internationale de l'Eclairage (CIE)].

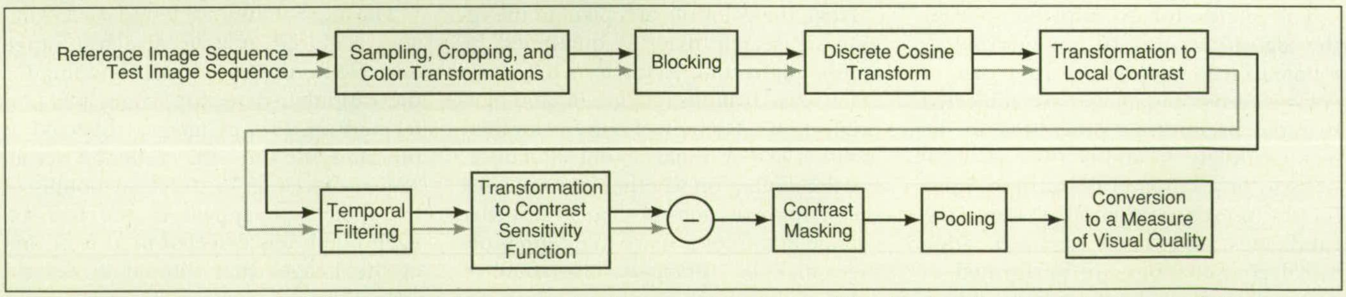
The sequences are then subjected to blocking and DCT, the results of which are transformed to local contrast (the ratio between the DCT amplitude and the mean amplitude in the affected block). The next step is a temporal-filtering operation, in which the temporal part of a contrast-sensitivity function (CSF) is implemented in a recursive discrete second-order filter. The outputs from the temporal-filtering operation are converted to just-noticeable differences by dividing each DCT coefficient by its respective visual threshold; this implements the spatial part of the CSF.

In the next step, the two sequences are subtracted. The resulting difference sequence is subjected to a contrast-masking operation, which also depends upon the reference sequence.

Finally, the masked differences can be pooled in various ways to illustrate the perceptual error over various dimensions. As used here, "pooling" signifies summing over one or more of six dimensions that represent, specifically, image frames, color channels, rows of blocks, columns of blocks, horizontal spatial frequencies, and vertical spatial frequencies. The pooled error can be converted to a measure of visual quality.

This work was done by Andrew B. Watson, James Hu, and John F. McGowan III of **Ames Research Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Information Sciences category.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Ames Research Center, (650) 604-5104. Refer to ARC-14236.



Test and Reference Sequences of digitized video images are processed to generate a measure of the visual quality of the test sequence relative to the reference sequence.

Infrastructure Software for Mining Image Data Bases

NASA's Jet Propulsion Laboratory, Pasadena, California

Diamond Eye is a computer program that enables a user equipped with only a personal computer, web-browser software, and a network connection to analyze large collections of scientific image data. The system is based on a distributed applet/server architecture that provides platform-independent access to image mining services. A user interacts with the system through a Java applet interface that is dynamically downloaded when a session is established. There is no need for the user to install "client" software or perform upgrades; the latest stable version of the applet is available automatically. Each server program is typically co-located with a large image repository to enable mining the data in place. Servers are also coupled with an object-oriented data base and a computational engine such as a network of high-perfor-

mance workstations. The data base provides persistent storage and enables querying of the "mined" information. The computational engine provides parallel execution of the most demanding parts of the data-mining task: image processing, object recognition, and querying-by-content operations. Diamond Eye is currently being used to locate and catalog geological objects in large image collections, but the design provides infrastructure for a range of scientific-data-mining applications. The system can be easily extended to incorporate domain-specific algorithms in any executable form (translation to the Java language is unnecessary).

This program was written by Michael Burl, Charless Fowlkes, Saleem Mukhtar, Joseph Roden, and Andre Stechert of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Software category.*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

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Refer to NPO-20921, volume and number of this NASA Tech Briefs *issue, and the page number.*

Software for Rapid Processing and Display of Earth Data

Goddard Space Flight Center, Greenbelt, Maryland

Digital Earth Workbench is a computer program that facilitates retrieval of Earth-related imagery and viewing of the imagery on either an ordinary computer video screen or a virtual-reality (head-tracked stereoscopic) display system. Examples of imagery that can be processed by this software include (but are not limited to) high-resolution topography, photographic images, maps, and images synthesized from geophysical data. Image data can be retrieved from storage at remote sites. The user can easily navigate to the data pertinent to any location on Earth and browse through imagery for that location. For images that are not topographical, the user can view the images overlaid on high-resolution Earth topography.

The development of Digital Earth Workbench was prompted by a desire for a system that is simple enough for use by a child and powerful enough to be useful to a scientist and that, in comparison with similar prior software, offers faster processing of image data and better performance as a virtual-reality interface. Digital Earth Workbench incorporates software components that exploit the capabilities of advanced computer hardware, mediate the exchange of data with virtual-reality display systems, implement advanced rendering concepts, and generate real-time graphical displays. These components are integrated in such a way as to focus them on displaying Earth-science data. The virtual-reality components of this software are particularly valuable because they provide an easy-to-use interface for obtaining three-dimensional-appearing views of data in relation to the Earth.

In this software, the topography of the entire surface of the Earth is divided into tiles. Each tile is further divided into subtiles. Each tile and subtile provide representations of the topography at several different levels of detail. As the user roams through geographically indexed data, the appropriate tiles, subtiles, and level of detail of each are selected on the basis of their proximity to the location selected by the user: this selection scheme limits the amount of graphical information that must be processed, so that the frame rate can remain high.

For overlaying images on Earth topography (and/or on a corresponding base Earth image), the software utilizes a multipass rendering mechanism. After the components of an overlay have been set up, the topography is redrawn, using the overlay information as texture superimposed on the topography. The redrawing process is limited to the largest topographical tile or subtile needed to encompass the overlay, in order to minimize the amount of geometrical information that must be processed. Multiple overlays are blended by use of common translucency techniques.

This work was done by Stephen Maher of **Goddard Space Flight Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Software category.*
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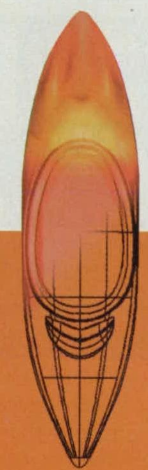

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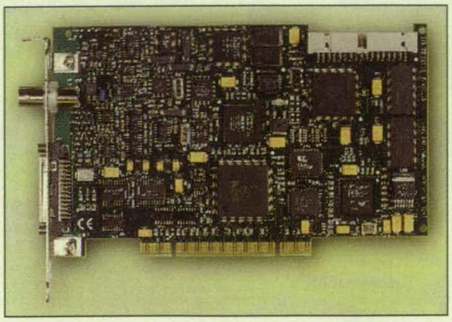
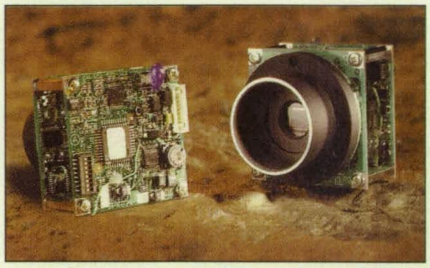


National Instruments, Austin, TX, offers the IMAQ™ PCI-1409 **image acquisition board** that features four video inputs and acquires images from standard and nonstandard cameras. Images with up to 1,024 gray scales or color images of stationary objects from NTSC, PAL, and RGB cameras may be acquired.

The board captures images in 8- or 10-bit mode at rates to 60 frames per second using a double-speed progressive scan camera. The board is suitable for use in industries from automotive and communications to pharmaceuticals. It comes with NI-IMAQ™ driver software, which uses one set of function calls for a variety of cameras, including slow or variable pixel clock and analog line scan cameras.

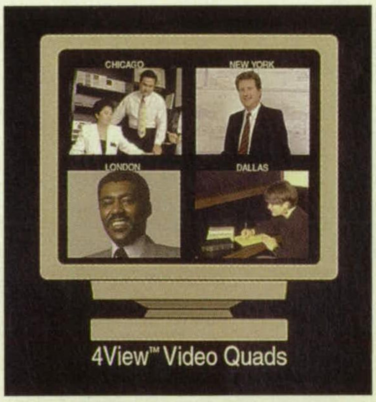
For More Information Circle No. 718



The BCV-M10 **board-level progressive scan camera** from JAI America, Laguna Hills, CA, provides two printed circuit boards, each measuring 1.57" square. One board contains 1/2"-format CCD sensor and driver circuits; the other includes timing and video circuits. The boards are permanently interconnected via a 2.17" flex cable that lets the boards be stacked or angled freely in relation to one another.

The board can be operated in a continuous mode at 25 progressive scan frames per second, or externally triggered using pulse width to govern shutter speed or edge-triggered for operation at a pre-set shutter speed between 1/50 and 1/10,000 of a second. The camera can provide synchronization in the form of HD/VD pulses. The unit also features a frame-delay readout mode that allows the captured image to be stored in the CCD sensor for a maximum of 80 ms.

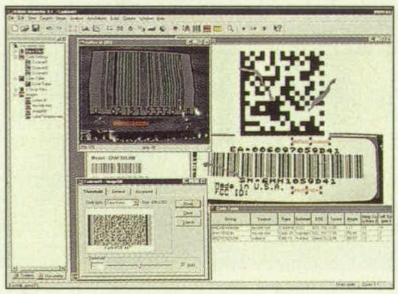
For More Information Circle No. 720



RGB Spectrum, Alameda, CA, offers the 4View™ **multi-video display processor** that takes four video inputs and displays them in quadrants on a monitor, flat panel, or projection screen. It allows all four video inputs to be displayed at full resolution on a 1280 x 1024 pixel screen. Display modes include four inputs in quadrants or full-screen display of any input.

Features include tilting, borders, and both front-panel and RS-232 control. Options include an auxiliary video rate output and DVI digital output, as well as the high-resolution RGB display. Models are available for projectors, monitors, and flat panels. Applications include teleconferencing, surveillance, and video monitoring.

For More Information Circle No. 721



Matrox Inspector 3.1 scientific/industrial **imaging software** from Matrox Imaging, Dorval, QE, Canada, is a Windows-based application for image capture, processing, analysis, display, and archiving. Based on the Matrox Imaging Library software development kit, the new version provides point-and-click access to image processing functions, blob analysis, gauging and measurement, and pattern matching.

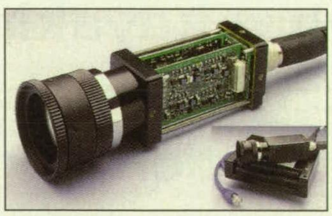
Other features include bar and matrix code recognition, watershed-based image segmentation, and support for image capture and image compression/decompression. The software includes workspace management tools, and is designed for scientists, technicians, and engineers in industrial inspection, microscopy, medical visualization, and biological analysis.

For More Information Circle No. 723

The In-Sight ID Reader from Cognex Corp., Natick, MA, is a self-contained, Ethernet-ready **machine vision sensor** designed to read 2D matrix and linear bar codes on parts. It combines a vision camera with vision processing technology, and reads up to 50 codes per second, including codes that have been poorly formed, distorted, or degraded. As the sensor reads 2D codes, it also provides verification metrics that can be used to monitor how well marking equipment is functioning.

The system requires no programming skills; basic code reading applications are set up using pre-configured application templates and set-up wizards. The reader can be integrated with PC-based control and operator interfaces found on marking systems and labelers via Ethernet, and with PLCs on the factory floor. The system comes with pre-installed software, and is available with accessories such as I/O modules, cables, LED-based lighting modules, and lens kits.

For More Information Circle No. 719



Wintriss Engineering Corp., San Diego, CA, offers the MachineCam **digital vision system** that consists of an area scan camera, a Motorola PowerPC® with 64 MB of memory, VxWORKS® real-time operating system, and Ethernet connectivity. The camera can operate alone in go/no-go inspection applications running custom programs. Designed for area scanning, the system comes with an image sensor that captures up to 30 frames per second at a resolution of 640 x 480 pixels.

Serial inputs/outputs include RS-232/422 communications outputs, 10Base-T Ethernet connection, NTSC video outputs for monitor connection, four product select inputs, six dedicated outputs, and general-purpose inputs/outputs. Its onboard processor enables programmers to develop custom applications using Tool Control Language (TCL), as well as C and C++. The system can be connected to Windows-based computers for camera initialization, inspection setup and testing, and inspection definition controls.

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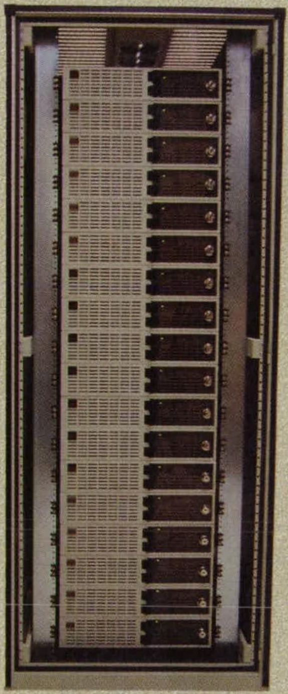

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Micromachined Broad Band Light Sources

Chip-based light source operates at high temperatures to produce high-brightness, white light.

NASA's Jet Propulsion Laboratory, Pasadena, CA, and Glenn Research Center, Cleveland, OH

A novel micromachined incandescent light source has been designed and fabricated to operate at temperatures exceeding 2,500 K. The high-temperature, tungsten filament-based source has a high-brightness, broad spectral band emission. The monolithic design allows for ease of incorporation with on-chip electronics as well as with fiber optics. Previously micromachined incandescent lamps contained, variously, tungsten or polycrystalline silicon filaments that glowed more dimly because they could only be operated at temperatures between 900 and 1,200 °C. The present devices can be used either in a single (discrete device) or two-dimensional array format for miniature spectroscopic instruments and for automotive dashboard displays.

A prototype light source was successfully operated at 2,500 K and has a spectral output closely resembling a simulated blackbody source at the same temperature (see Figure 1). The fabrication process is outlined schematically in Figure 2. The source is based on a modular design and consists of three separately micromachined chips that are subsequently

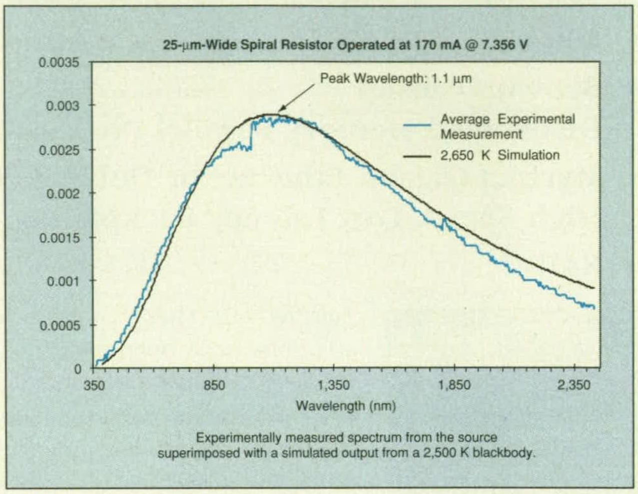

Figure 1. **An Experimentally Measured Spectrum** is shown from the source superimposed with a simulated output from a 2,500 K blackbody.

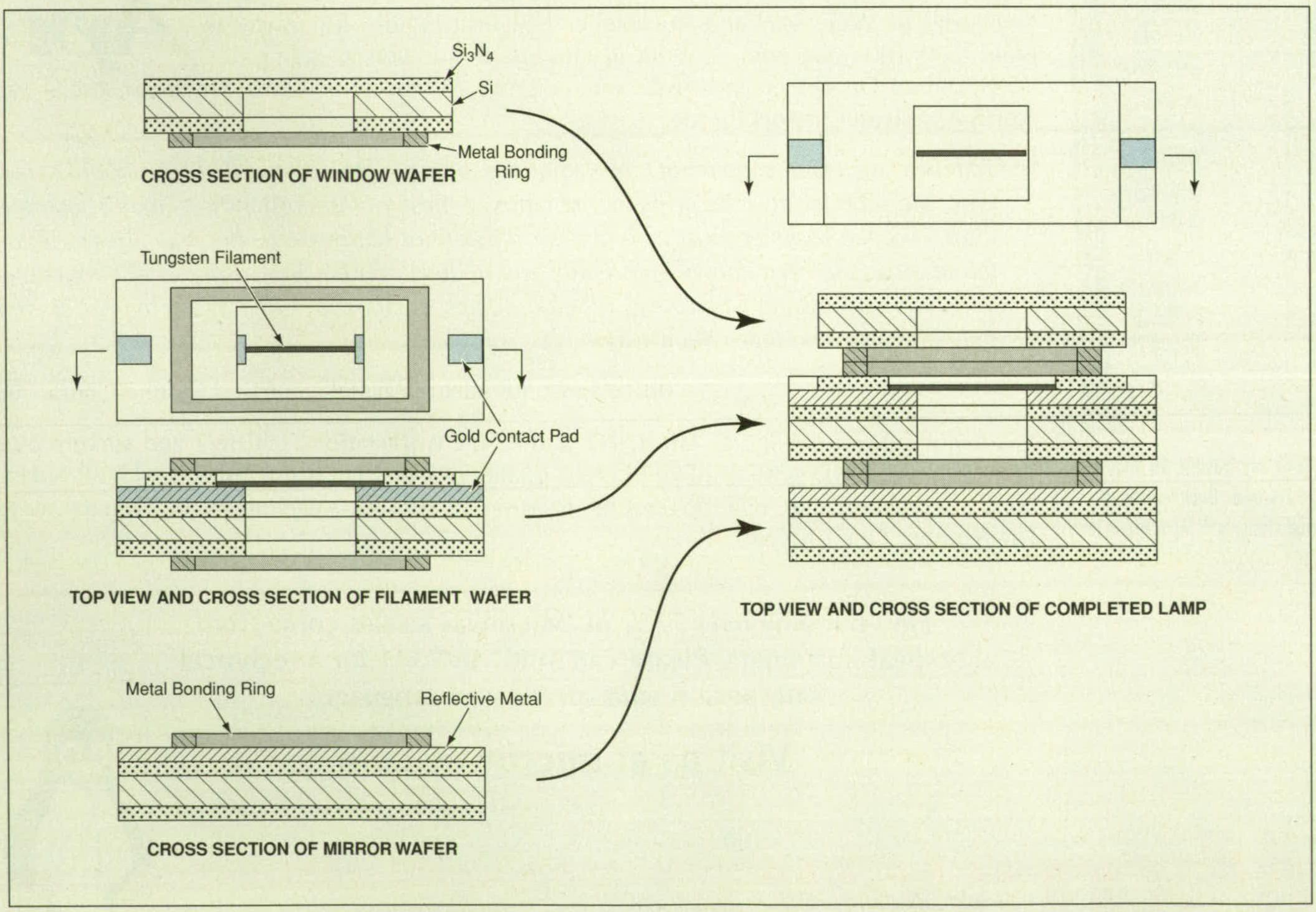

Figure 2. **Following a Modular Approach to Design and Fabrication,** an incandescent lamp is fabricated by micromachining three wafers, then bonding them together.

bonded together. The three chips consist of one that includes the tungsten filament, one that includes a reflective mirror, and one that includes an encapsulating transmission window. Each chip starts out as part of a Si wafer that is coated with an insulating layer of SiN.

To form the mirror chip, a highly reflective metal is deposited on one face of the wafer. Then a metal ring for subsequent wafer-to-wafer bonding is deposited on the mirror surface. The processing of the filament chip is more complex. First, gold contact pads for the tungsten filament are deposited on one surface of the wafer. An electrically insulating layer of SiO_2 is deposited over the contact pads and the rest of this face. Metal rings for subsequent wafer-to-wafer bonding are deposited on both the SiO_2 layer and the opposite SiN face of the wafer. A central hole destined to become the evacuated light source chamber is patterned and etched through the Si and SiN layers. The SiO_2 layer is patterned and etched to expose the contact pads. The tungsten filament is installed, either by bonding a commercially available thin tungsten wire onto the contact pads, or by attaching a micromachined tungsten filament or by the deposition and patterning of tungsten thin films. Following installation of the filament, the remaining layer of SiO_2 extending within the lamp chamber is etched away. Processing of the window chip begins with the deposition of a bonding ring on face of the wafer. The window is patterned on the bonding-ring face and then the SiN and Si layers are etched away in the window area, leaving only a window of SiN on the face opposite the bonding ring. Finally, the window, filament, and mirror wafers are bonded under vacuum or a controlled atmosphere.

This work was done by Thomas George and Eric Jones of Caltech for **NASA's Jet Propulsion Laboratory**, *in collaboration with Margaret Tuma of* **NASA's Glenn Research Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Components and Systems category.*

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Refer to NPO-20655, volume and number of this NASA Tech Briefs *issue, and the page number.*

Automatic Bias Compensation in GPS Receivers

Errors caused by unintended variations in electronic components are corrected.

NASA's Jet Propulsion Laboratory, Pasadena, California

A technique of automatic bias compensation has been devised to correct errors caused by variations among electronic components in Global Positioning System (GPS) receivers that use the coarse/acquisition (C/A) GPS code. Even though there are large government and commercial markets for such GPS receivers, these errors have not been generally understood. [Alternatively or in addition to the automatic-bias-compensation technique, the errors can be reduced by (1) building GPS receivers from components of higher quality (that is, components that have lower manufac-

turing tolerances and are less susceptible to aging) and (2) performing more extensive manual adjustments during integration and testing of GPS receivers.]

The errors in question are sampler biases, which can interact with GPS signals in such a way as to introduce spurious signals that can confuse affected receivers. The effect of these errors is more pronounced at the high Doppler shifts in signals received by a GPS receiver aboard an orbiting spacecraft or other high-speed vehicle. The automatic-bias-compensation technique is implemented in the digital signal-processing portion of a GPS receiver. The digital samples of amplified received signal + noise are measured for a bias. Corrections are computed and written over the incoming samples to drive the resulting bias to zero, which also reduces the signal-to-noise level. This process is controlled by a feedback loop to adapt automatically to variations in the level of uncorrected bias coming from the sampler.

This work was done by Lawrence Young, Jeffrey Tien, and George Purcell of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Components and Systems category.*

NPO-20819

CMOS Image Sensors Capable of Time-Delayed Integration

This will enable CMOS to perform a function previously limited to CCDs.

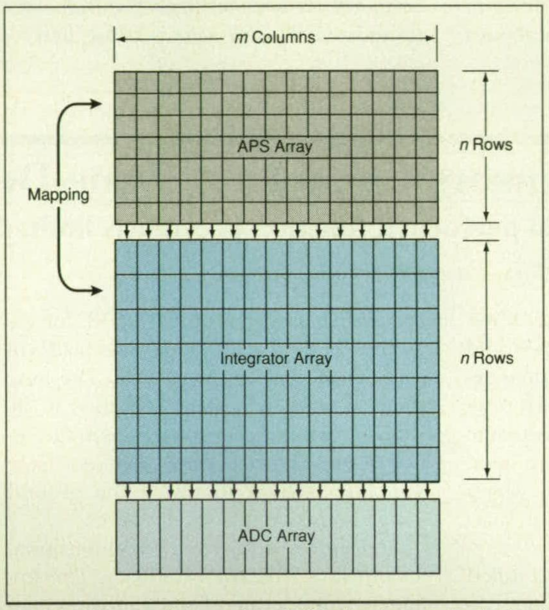
NASA's Jet Propulsion Laboratory, Pasadena, California

Complementary metal oxide/semiconductor (CMOS) image sensors would be capable of operation in a time-delayed-integration (TDI) mode. Heretofore, the only semiconductor electronic image sensors capable of TDI have been charge-coupled devices (CCDs), which have dominated the image-sensor market for nearly all applications.

TDI is an advancement upon so called "push broom" imagers in which a one-dimensional imager array (1 × 512, for example) is used from a moving platform such as an airplane or satellite. The long dimension in such imagers is used to divide the ground scene into pixels in the lateral or so-called cross-track direction. Time sampling is used to divide the ground image in the along-track direction.

TDI imagers use a two-dimensional array (32 × 512, for example). The imager is still operated from a moving platform using the "push broom" scheme, however, as a ground pixel moves across the pixels of the imager in the along-track direction (along the 32 pixels of the column in the example above), the TDI imager multiply samples the same ground pixel and then sums or averages these multiple samples in order to improve the signal-to-noise ratio as compared with a simple, one-dimensional push broom imager.

CCDs are ideally suited for TDI, because they use noiseless summing of charge packets, and because the charge packets are naturally moved across the image plane during readout in a CCD. It is a simple matter to essentially move the charge packet in time with the motion of the associated ground pixel. Unfortunately, CCDs are inherently fairly high-power devices (consuming on the order of watts) and their fabrication processing is not fully compatible with integrated CMOS electronics. CMOS imagers have the ability to operate with much lower power (on the order of tens of milliwatts) and allow the integration of control electronics and signal processing on-chip, in order to enable the development of highly compact complete imaging systems, including even analog-to-digital conversion on-chip. The development of low-noise switched capacitor circuitry, as well as the development of the CMOS active pixel sensor (APS) visible imager, have made it possible in principle to realize TDI in the proposed CMOS image sensors. As shown in the figure, a device according to the proposal would include a CMOS 32 × 512 APS array connected column-wise to a 32 × 512 array of low-noise, high-speed analog charge integrators. These are followed by a one-dimensional array of column-parallel cyclic architecture analog-to-digital converters that service the column-parallel array of integrators.



TDI Would Be Implemented in CMOS Circuitry on the basis of an architecture in which APS pixel rows would be mapped to the rows in the array of integrators.

As a ground pixel moves its focus from pixel to pixel along the column of the APS array, the signal from this ground pixel is multiply sampled, and each sample is integrated onto the storage capacitor on one integrator in the integrator array. Since the ground pixel moves from pixel to pixel in the imaging array, the TDI imager must continually keep track of which pixel's output is added to which integrator. After a given ground pixel has moved through all 32 rows, the output of the corresponding integrator is sent to the ADC for digitization, and the integrator is reset so that it can begin the integration of the new ground pixel that moves into the field of view. Of course, all 32 pixels in the column must be connected in turn to the appropriate integrators in the time it takes for a ground pixel to move from one imager pixel to the next. The signal is dumped in a snapshot mode that eliminates motion artifacts that would otherwise be caused by the fact that each imager pixel is addressed at a slightly different time.

Within the general layout and mode of operation described above, the proposal encompasses several alternative operating schemes and readout-circuit designs. Each represents a different trial solution to achieve optimum performance with re-

gard to sensitivity, low power consumption, high-speed digital readout, and minimization of the non-imaging-area of the chip. These schemes and designs are too complex to describe within the space available for this article; interested readers should request more information, as noted below.

This work was done by Bedabrata Pain, Thomas Cunningham, Guang Yang, Monico Ortiz, and Brita Olson of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Components and Systems category.*

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Ceramic Ribbons as Waveguides at Millimeter Wavelengths

Very low loss can be obtained in a dominant TM-like mode.

NASA's Jet Propulsion Laboratory, Pasadena, California

Theoretical calculations verified by experiments have shown that suitably designed ribbons made of alumina can serve as low-loss dielectric waveguides for electromagnetic radiation at frequencies from 30 to 300 GHz. Prior to this development, low-loss waveguides for this frequency range were unknown. The achievable attenuation factor for an alumina-ribbon waveguide is less than 10 dB/km; as such, it is less than a hundredth of that of a typical ceramic dielectric rod waveguide, less than 1/200 of that of a customary metallic waveguide, and less than 1/300 of that of a microstripline at a frequency of 100 GHz.

The exceptionally low loss factor is not achieved primarily, as it has been on some past occasions, through selection of ultra-low-loss dielectric material (since ultra-low-loss material is not obtainable in this frequency range). Instead, it is achieved primarily through selection of a cross-sectional geometry in conjunction with a reasonably low-loss dielectric material of suitable relative permittivity to support electromagnetic propagation in an inherently low-loss waveguide mode. In such a mode, the dielectric core (in this case, the alumina ribbon) acts as a surface waveguide: The interaction of the propagating electromagnetic wave with the dielectric core (and thus the attenuation) is minimal because the field configuration of the mode is such that only a small fraction of the electromagnetic energy propagates along the dielectric core while the remaining major part of the electromag-

netic energy propagates, parallel to the ribbon, through the surrounding free space.

The attenuation coefficient (α) of a dominant mode guided by a simple solid dielectric waveguide surrounded by lossless dry air depends on the loss factor and the permittivity of the dielectric material as well as the size and shape of the waveguide and the electromagnetic-field configuration in the particular mode. The equation for the attenuation coefficient is

$$\alpha = (8.686\pi/\lambda_0)\varepsilon_1 R\tan(\delta_1),$$

where λ_0 is the free-space wavelength in meters, ε_1 is the relative permittivity of the dielectric material, R is a ratio between two integrals that depend on the electromagnetic-field configuration in the particular mode, and δ_1 is the loss tangent of the dielectric material. The product $\varepsilon_1 R$ is of particular significance and is denoted the geometric loss factor.

A systematic study involving computation of α for a variety of dielectric materials and cross-sectional geometries was performed. This study led to the following conclusions (among others):

- A ceramic ribbon waveguide can support two dominant modes with no cutoff frequency — a transverse electric (TE)-like mode with most of its electric field aligned parallel to the major axis of the cross section of the ribbon, and a transverse magnetic (TM)-like dominant mode with most of its electric field aligned parallel to the minor axis of the cross section.
- Unlike the TE-like mode, the TM-like mode is a low-loss waveguide mode as described above. In the TM-like mode, a suitably dimensioned ribbon waveguide made from alumina or other low-loss, high-permittivity ceramic can exhibit an attenuation coefficient of less than 0.005 dB/m.
- Whereas the geometrical loss factor of a circular rod is very sensitive to changes in diameter, that of a ribbon is insensitive to small changes in cross-sectional area. This signifies that the TM-like mode on the ribbon is very stable in the sense that it is not easily disturbed by geometrical imperfections.

The figure shows measured and calculated attenuation coefficients for the low-loss dominant mode in several different waveguide structures, including alumina ribbons with an aspect ratio (width÷thickness) of 10 and three different loss-tangent values. These and other data show that high-aspect-ratio alumina ribbons are suitable as low-loss waveguides, opening up possibilities for the development of communication systems operating in the 30-to-300-GHz frequency range.

This work was done by Cavour Yeh, Farzin Manshadi, Phillip Stanton, Vahraz Jamnejad, William Imbriale, and Fred Shimabukuro of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Components and Systems category.*

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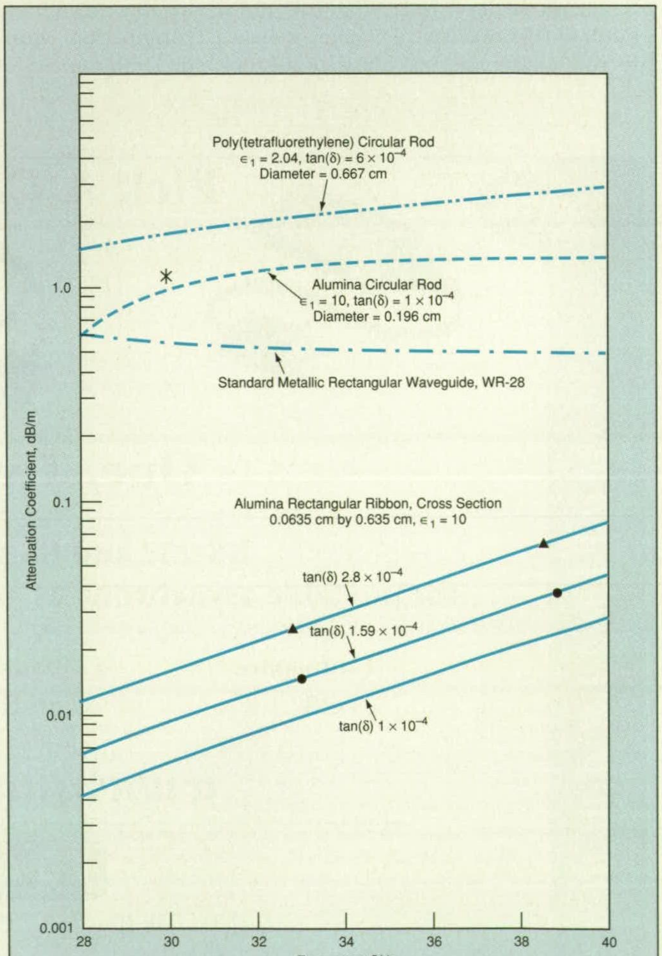

Attenuation Coefficients for several dielectric waveguides were computed theoretically for the frequency range of 28 to 40 GHz. Measured values are indicated by a few data points (*, ▲, •).

Multithreading Program for Retrieval of Optical Phase Fields

A multithreading computer program performs phase-retrieval and -unwrapping calculations to extract accurate image phase maps from noisy image magnitude fields generated by adaptive optics. [As used here, "phase retrieval" signifies the calculation of phase map modulo 2π, while "unwrapping" signifies the elimination of the integer-multiple-of-2π phase ambiguity.] The program includes a MATLAB front-end script integrated with a multithreaded computing kernel in a set of C routines. The MATLAB script controls the flow of computations and provides a graphical user interface. Major computations are performed in C routines, wherein multiple computing threads are generated to parallelize the computations. The MATLAB script starts the C routines through a function call using MATLAB's MEX interface, and the results of the computations are returned from C routines to the MATLAB script. The program parallelizes the computations whenever multiple central processing units (CPUs) are available; this feature reduces the execution time significantly. Because MATLAB is popular in engineering computing, and increasing numbers of computers are equipped with multiple CPUs and multithreading software libraries, this program has significance beyond the original adaptive-optics application as an example of how to do high-performance engineering computing at relatively low cost.

This program was written by Scott Basinger, John Lou, and David Redding of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Software category.*

This software is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-20848.

Software for Analyzing Earth/Spacecraft Radio Interference

The Spectral Analysis Tool (SAT) computer program assists in analysis of interference between radio signals in Earth/spacecraft communications. SAT provides an easy-to-use interactive graphical interface with a menu for selecting among the following utility subprograms: an editor for modulated signal and interference sources of various spectral widths, an editor for inserting an interfering sine wave into the spectrum, a filter editor for simulating effects of a band-limited channel, and a graphics editor for viewing and textual editing of power spectra and spectral-density plots. Also provided are calculators for signal and interference bandwidth and power, plus communication-link-budget tables and interference-analysis tables with choices of antennas, amplifiers, and receivers. The main output of SAT comprises data on interference-to-signal power ratios and system losses with respect to interference-free baseline systems. Optionally, SAT generates color or gray-scale spectral plots or information in textual (including tabular) form on results of power calculations, link-budget parameters, or any other parameter(s) of interest. SAT has been written for execution on a desktop computer running the 3.1, NT, or 95 version of the Windows operating system. The complete SAT software package fits on a standard 3.5-in. (8.89-cm) diskette.

This program was written by K. Oudrihiri, K. Angkasa, Leon Truong, E. Kidd, Victor Lo, Mazen Shihabi, F. Chen, J. Rucker, John Gevargiz, and K. Widyono of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Software category.*

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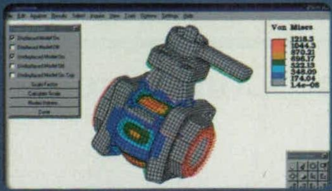
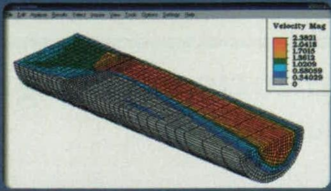
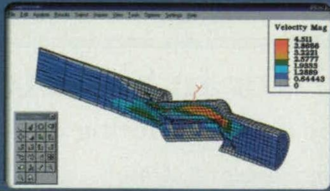
12 Reasons Why Algor Should Be Your FEA Partner



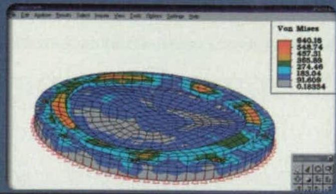
Linear Static Stress - Algor's linear static stress product enables you to capture complex assemblies, such as this valve assembly, from a CAD solid modeler and run a finite element analysis using fast solver technology. Typical loadings are pressure, acceleration, temperature, force and prescribed displacements.



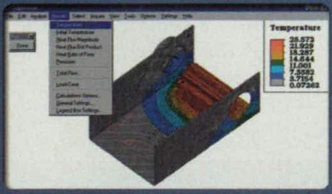
Steady Fluid Flow - Prescribed velocities and pressures provide the loading for this 3-D steady fluid flow analysis of a pipe with a gate valve. Algor's multiple load curves allow for easy data entry for adding loading such as gravity.



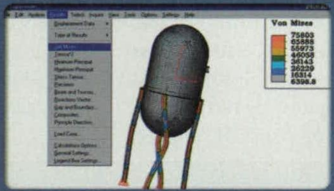
Unsteady Fluid Flow - Unsteady fluid flow of this ball valve system was analyzed using a 3-D CAD solid model. Algor's unique processor solves for velocities and pressures throughout the dynamic event, using a specialized meshing algorithm for high velocity gradients.



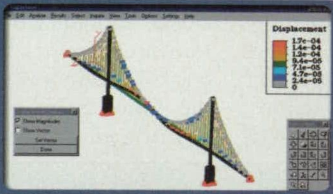
DDAM - Algor's Dynamic Design Analysis Method enables you to analyze the shock response at the mountings of shipboard equipment such as watertight doors, masts, propulsion shafts, rudders, exhaust uptakes and portholes, as shown above.



Transient Heat Transfer - The dynamic effects of a transient heat transfer analysis were needed for the time-dependent temperature loading of this heat sink assembly. Algor's multiple load curves for various loading conditions allow for the simulation of the thermal event.

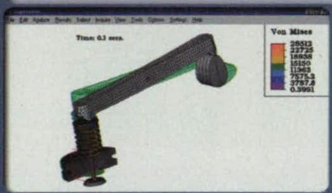


Nonlinear Static Stress - Algor's nonlinear product helps to accurately predict large deformation and large strains caused by static loading. As seen by this water tank, buckling of a structure is one type of failure that can be exposed.

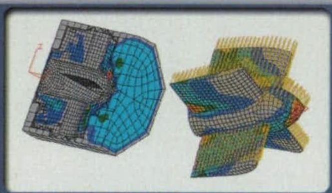


Linear Dynamic Stress- A modal analysis is one of the linear dynamic stress analyses performed on this suspension bridge. Failure can occur when the loading frequency is at the structure's resonant frequency. Algor's linear dynamic analyses accurately predict these frequencies and dynamic effects.

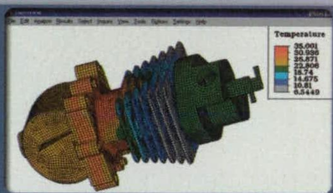
Mechanical Event Simulation (MES) with Nonlinear Material Models - Algor's MES extends full dynamic analysis capabilities to large strain/deformation analyses of nonlinear materials, as shown by this landing gear assembly. Kinematic elements can be used for quicker processing.



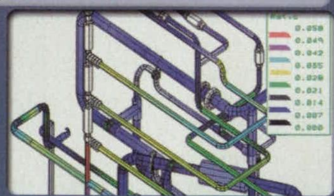
Mechanical Event Simulation (MES) with Linear Material Models - Algor's MES with linear material models allows you to represent a dynamic analysis while solving for kinematics, deflections and stresses of the structure. Analyses using large CAD assemblies, such as this rocker arm assembly model, can be expedited by using kinematic elements.



Multiphysics - Algor's multiphysics products enable you to combine multiple analysis types into one event. Resultant forces from flow around this turbine were calculated and then projected onto the object for a structural analysis. Other multiphysics capabilities include combining heat transfer with fluid flow, heat transfer with static/transient stress and heat transfer with fluid flow and stress.



Steady-State Heat Transfer - Algor's steady-state thermal processor helps predict temperature distribution due to thermal loading. Loading such as convection, radiation, conduction, applied temperatures and surface heat fluxes can be added to an analysis for fast, accurate results. In the case of this engine casing, both conduction and convection were part of the analysis of this 3-D solid model.



Piping Design and Analysis - Algor's piping design and analysis product enables you to calculate the deflections and stresses of this plant piping system and then compare the results with ASME/ANSI code allowables. Loadings can include: dead weight, thermal differences, pressure, wind loads, earthquake loads, time history of forces/displacements, response spectrum, natural frequencies and pitch and roll.

Algor has been developing FEA software since 1978.
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"Smart Coatings" for In Situ Monitoring of Engine Components

Incipient failures could be detected during operation.

John H. Glenn Research Center, Cleveland, Ohio

"Smart coatings" denotes a class of high-temperature-resistant, multilayer, thin (total thickness < 10 µm) films that contain predominantly planar layers of sensor circuitry sandwiched between tough, protective, electrically insulating layers. These films are being developed to enable *in situ* monitoring of aircraft engines during flight or inspection. "Smart coatings" could be deposited on turbine and compressor blades, turbine-blade hubs, and other critical engine parts to detect incipient failures and other adverse phenomena.

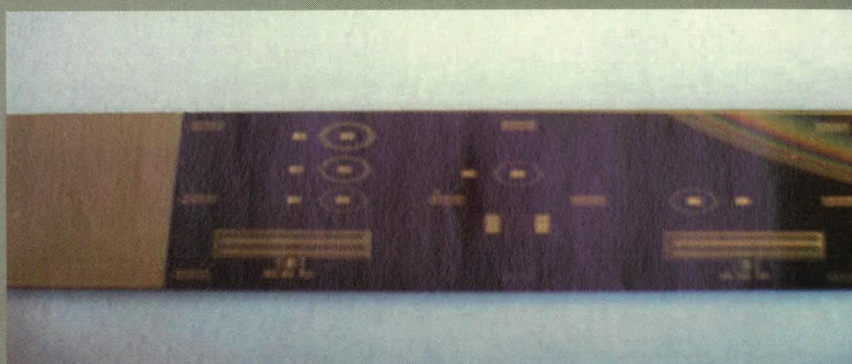
The concept of "smart coatings" incorporates and extends the concept of wireless resonant crackwires, described in "Resonant Crackwires for *In Situ* Monitoring of Jet Engines" (LEW-16758), *NASA Tech Briefs*, Vol. 24, No. 6 (June 2000), page 8a. Experimental "smart coatings" that have been developed thus far include not only crackwires (for detecting cracks and plastic deformation at instrumented surfaces) but also eddy-current sensors for detecting plastic deformations below the instrumented surfaces, and capacitive sensors for detecting surface contamination (e.g., fuel, ice, or liquid water).

The figure shows some nickel-alloy coupons with experimental "smart coatings." In preparation for fabricating the thin-film sensors, each coupon was ground flat and polished. Each coupon was then coated with an insulating layer of either SiO_2 or Al_2O_3. Next, thin-film aluminum conductors of sensor circuits were fabricated on the insulating layers by use of photolithographic and deposition techniques and equipment like those used to manufacture integrated circuits.

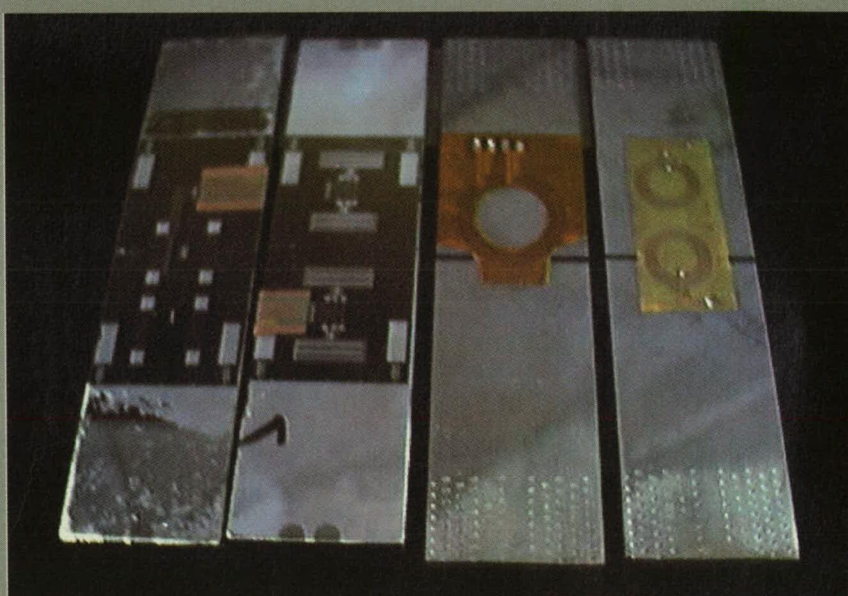
Tests of coupons containing eddy-current and crackwire sensors have demonstrated that these sensors can detect cracking and plastic deformation. Tests of a capacitance sensor showed that the sensor could detect such surface contaminants as fuel, water, and ice. Tests also revealed that of the two types of sensors for detecting cracks and plastic deformations, crackwires are more practical for use as wireless crack detectors (wireless in the sense that they would be interrogated by radio).

This work was done by Bruce W. McKee, Scott R. Dahl, and Ekaterina Y. Shkarlet of Innovative Dynamics, Inc., for **Glenn Research Center**.

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-16919.



SENSORS DEPOSITED ON ALUMINUM OXIDE



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Aggregate-Search Approach for Planning and Scheduling

NASA's Jet Propulsion Laboratory, Pasadena, California

Several algorithms developed for use in automated planning and scheduling of sets of interdependent activities employ aggregation techniques to increase the efficiency of searching for temporal assignments that are legal in the sense that they do not violate constraints. In the aggregate-search approach, one computes the aggregate state and resource requirements of a cluster of interdependent activities and searches for minimally conflicting temporal placements for the corresponding cluster of requirements. During the search, all activities that temporally constrain each other (for example, as in the requirement to complete activity A before starting activity B) are moved in unison. In computational tests based on a synthetic planning and scheduling problem and on problems from spacecraft and Rocky-7 Mars Rover operations, the aggregation-search algorithms were found to out-perform alternative algorithms that follow the "naïve" approach of searching for legal placements of the constituent activities individually.

This work was done by Steve Chien, Russell Knight, Gregg Rabideau, and Robert Sherwood of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Materials category.*

This software is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-20660.

Improvements in Electroformed Copper Alloys

Greater strength and ductility can be obtained by modification of plating conditions.

John H. Glenn Research Center, Cleveland, Ohio

This **Tube-Bundle Chamber** with a complex shape was fabricated by electrodeposition of copper onto formed copper tubes held in place on a mandrel. No high-temperature joining process was used at any stage of fabrication.

Some success has been achieved in a development program directed toward improving the mechanical properties of electroformed copper-alloy structural components. Typical of such components are bundles of tubes and other heat-exchange devices that have complex shapes. Electroforming of copper alloys is an attractive means for manufacturing such a component because of the high thermal conductivity of copper and because electroforming both produces the alloy and forms the component in nearly net shape in a single process.

Prior to the efforts reported here, electroformed unalloyed copper and copper alloys were found to be too weak for some applications and to lose mechanical strength at moderate operating temperatures. Electroformed nickel — the traditional electroformed structural material — has mechanical properties that are more than adequate for many applications, but its thermal conductivity is less than that of copper. Thus, there is a need to be able to electroform unalloyed or low-alloy copper to obtain high thermal conductivity while producing components strong enough to compete with nickel components at temperatures up to and beyond 200 °C (392 °F). Electroformed copper components could then be used more widely in applications that involve higher temperatures.

The specific objectives and achievements of the program were the following:

- An effort to develop copper or copper alloy electrodeposits having mechanical

properties competitive with those of electrodeposited nickel was successful. Although a tensile strength of 689 MPa (100 kpsi) was exceeded in limited samples, it was not possible to maintain this level of strength during the long electroforming process times encountered in production facilities. Tensile strengths of 517 to 551 MPa (75 to 80 kpsi) accompanied by acceptably large yield strength and ductility were found to be practical in production deposits from an acid copper sulfate bath containing a single proprietary high-molecular-weight organic polymeric additive called "PEG-B." These deposits responded well to heat treatments at temperatures from 149 to 371 °C (300 to 700 °F) and were found to retain yield strengths far higher than that of wrought annealed oxygen-free high-conductivity (OFHC) copper. Unlike typical acid copper electrodeposits, these materials exhibited acceptably large ductility at elevated temperature.

- An effort to make low-additive, non-alloyed electrolytic copper deposits with yield strengths of at least 49.7 MPa (7.2 kpsi) and 10-percent elongation at 371 °C (700 °F) was partially successful: The goals were not achieved at 371 °C (700 °F), but were achieved at 260 °C (500 °F) with deposits from acid copper sulfate baths containing single additives. In each case, the single additive was either chloride ions, xylose, triisopropanolamine, or PEG-B.
- Partial success was achieved in an effort to demonstrate low-alloy-copper deposits with resistance to recrystallization at temperatures up to 500 °C (932 °F) and strengths greater than those of traditional copper deposits. All of these deposits were found to recrystallize to some degree at 371 °C (700 °F). However, after heat treatment at 371 °C (700 °F), deposits from acid bath that contained certain additives exhibited mechanical strengths greater than those of traditional copper deposits; in each case, the additive was either a combination of triisopropanolamine and D+ xylose, a dispersion of submicron-sized α and γ alumina particles, or PEG-B. It was also demonstrated that electrodeposited copper alloyed with a small amount of platinum is a heat-treatable material that exhibits an excellent microstructure after one hour at 371 °C (700 °F), outstanding ductility, and yield strength far greater than that of traditionally electrodeposited copper or wrought annealed copper.
- It was shown that fullerenes could be codeposited with copper to form a dispersion alloy of superior strength with no loss of thermal conductivity. It was also shown that dispersion strengthening could be achieved by codeposition of copper alloys (including copper-platinum alloys) with submicron alumina particles.
- The figure depicts the interior of a tube-bundle thrust chamber (part of a rocket engine) designed and fabricated by electroforming of copper, taking advantage of the developments described above. This is the first tube-bundle thrust chamber made entirely without welding, brazing, or other thermal joining processes; the avoidance of such processes makes it possible to preserve the desired mechanical properties of the copper.

This work was done by G. A. Malone, W. Hudson, B. Babcock, and R. Edwards of Electroformed Nickel, Inc., for **Glenn Research Center**. *For further information, access the Technical Support Package (TSP) **free on-line at www.nasatech.com** under the Materials category.*

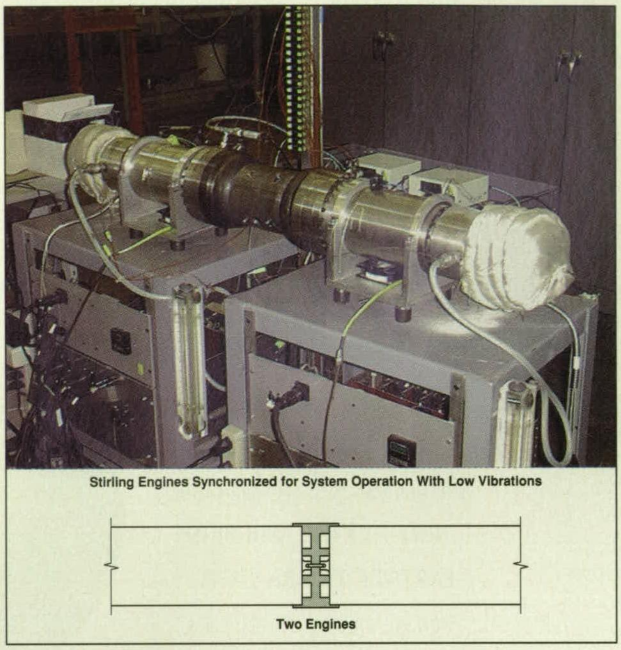
Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-16887.

Machinery/Automation

Dynamic Balancing of Multiple Independent Stirling Engines

Vibrations are minimized without sacrificing redundancy.

John H. Glenn Research Center, Cleveland, Ohio



Housings of Multiple Free-Piston Stirling Engines are rigidly connected at their cold ends so that vibrations are coupled among them. The arrangement is symmetrical so that their piston motions will balance if properly synchronized. Experiments have shown that synchronization is achieved when the engine electrical outputs are ac-coupled.

Experiments have shown that an assembly of multiple free-piston Stirling engines can be designed and constructed in such a way as to both (1) make the vibrations of the engines balance each other to minimize the overall level of vibration, and (2) enable the engines to operate independently of each other, so that if one fails, the other(s) can continue to provide power. Prior to these experiments and to the research and development effort that preceded them, it was not possible to achieve both redundancy and suppression of vibrations: The only previously demonstrated method to balance out vibrations of multiple Stirling engines was by use of counter-oscillating pistons coupled to each other via a common thermodynamic hot space, with the engines driving linear alternators connected electrically in series. This older scheme precludes redundancy because the common thermodynamic interaction and the series electrical connection causes both engines to fail when one fails.

In the present scheme, the multiple Stirling engines in a given assembly are thermodynamically independent of each other. For coupling of vibrations between the engines, the housings of the engines are rigidly connected to each other at their cold ends in an opposed arrangement (see figure). A tuning capacitor is connected in series with the linear alternator of each engine to compensate for the alternator inductance in order to obtain a near unity power factor.

The experiments were performed on a two-engine assembly operating at a frequency ≈60 Hz and output-power levels ≤250 W per engine. When the electrical outputs of the engines were ac-coupled in parallel downstream of the tuning capacitors, the net vibration level was reduced to as little as 1/50 of that of a single engine operating alone. (DC coupling was found to exert no effect on vibrations.) It was observed that the ac connection between the two engines can be opened or closed at will with no adverse consequences other than that when the connection is opened, the engines gradually drift out of synchronization and thus vibrations are no longer suppressed.

When the ac connection is closed after having been open, the engines come back into synchronization with opposing piston motions, so that vibrations are once again suppressed. When so synchronized, the engines remain synchronized even in the presence of wide variations in charge pressure or hot-end temperature of one engine relative to the other. No significant transient overstrokes or other potentially damaging behavior was observed.

This work was done by Maurice A. White, Laurence B. Penswick, and Songgang Qiu of Stirling Technology Co. for **Glenn Research Center.**

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-16823.

Using Artificial Neural Networks To Monitor Stirling Engines

Minimal, noninvasive instrumentation can be used.

John H. Glenn Research Center, Cleveland, Ohio

An important secondary topic addressed in the research and development effort described in the preceding article is the use of artificial neural networks to improve the monitoring and thus the control and safety of multiple free-piston Stirling engines. Information collected by monitoring subsystems constitutes essential feedback for use by control and safety subsystems. This information includes such externally measurable quantities as heater-head temperatures, motions of engine housings, and output currents and voltages.

(*continued on page 60*)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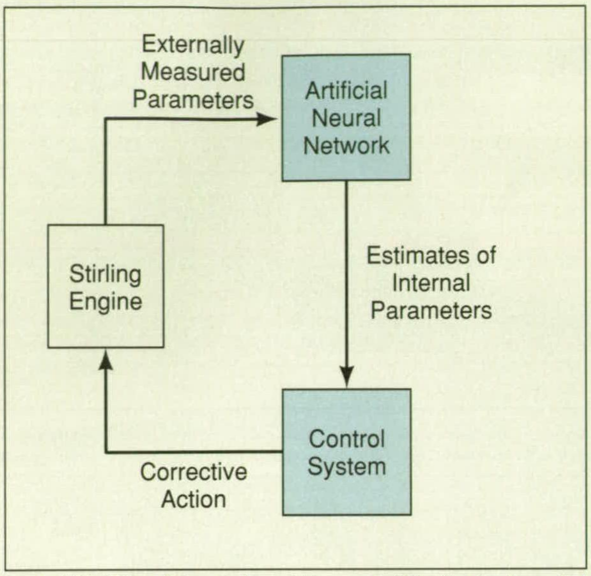


An **Artificial Neural Network** could be part of the feedback control system of a Stirling engine or an assembly of such engines. The neural network would estimate internal operating parameters (e.g., pressure or piston motions) from externally measurable quantities (e.g., output current, output voltage, and current/voltage phase angle).

Prior to this effort, typical approaches to the monitoring and control of Stirling engines involved the use of extensive data-acquisition systems that collected, in addition to externally measurable quantities, such critical internal operating parameters as pressures and motions of components as measured by invasive pressure and position probes, respectively. Unfortunately, such probes are expensive, are potential sources of failure, and compromise design options.

The neural-network approach offers an inexpensive, simple, and highly reliable alternative to the use of invasive probes. An artificial neural network can be particularly useful for modeling and monitoring a complex mechanical/electrical system like a Stirling engine, for which the mathematical relationships among input and output variables are either unknown or too complex to be represented by an analytical model. The basic idea is to train an artificial neural network to infer information about internal operating conditions from measurements by minimal (only external) instrumentation in order to detect actual or incipient failure or deterioration.

An autonomous control system could process the output of such a neural network (see figure) into control commands to perform corrective actions to maintain reliable engine operation. For example, in the case of two or more Stirling engines operating in synchronization as described in the preceding article, a neural network could compensate for deterioration of one of the engines by triggering a command to ramp down the output of that engine and ramp up the output(s) of the other engines. The feasibility of this neural-network concept was demonstrated in an experiment on two coupled Stirling engines: While one engine was operated under nominal conditions, the other was operated at a series of reduced pressures to simulate the effects of a slow leak. An artificial neural network, fed only data on root-mean-square currents, output power, and current/voltage phase angles from the two engines was found to infer the decrease in pressure in the affected engine with high accuracy.

This work was done by Laurence B. Penswick of Stirling Technology Co. for **Glenn Research Center**.

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-16822.

Tooling for Controlled Grinding of an Edge To Remove Defects

Worker fatigue, process time, and risk of scrapping expensive workpieces are reduced.

Marshall Space Flight Center, Alabama

A special-purpose grinding tool and fixtures have been developed for reworking an edge of a seal surface on a nozzle-throat-support housing in a rocket engine (see Figure 1) to remove defects caused by corrosion. Although the design of the tooling is specific to the original rocket-engine application, some aspects of the design may stimulate thinking about solutions to other special machining problems that cannot be solved readily by use of standard tooling alone.

According to the engineering specification that governs the rework of the seal surface, the radial depth of edge material removed must not exceed 0.032 in. (0.81 mm). Previously, the rework involved the manual filing of the edge. The filing procedure was difficult to control; the maximum allowable depth was sometimes exceeded, making it necessary to scrap the housing. The present tooling was developed to provide greater accuracy and reliability in reworking the seal surface and to prevent removal of edge material beyond the maximum allowable radial depth.

The tooling (see Figure 2) includes a base fixture equipped with indexing bearings that ride along datum surfaces of the throat-support housing. The base is secured to the housing by spring-loaded pincher bearings on the inside and a spring-loaded pivot bearing on the outside. An adjustable outrigger bearing adds stability and provides for alignment of the index bearings. Two precise linear shafts that have been press-fit into the base fixture serve as supports and guides for the grinding tool.

The grinding tool is an automotive valve-seat grinding stone on the shaft of a low-speed air motor. A cradle that is positioned between the two shafts and that rides along the shafts on bushing bearings holds the motor at the angle needed to enforce the correct alignment of the grinding stone with the surface of the workpiece.

A micrometer on the base fixture is used to adjust the position of a hard stop that limits the depth of grinding; this adjustment is performed before grinding. During grinding, a technician applies gentle, radially outward force to the cradle while moving the base fixture circumferentially to make a smooth transition to the workpiece surface adjacent to the defect to be removed.

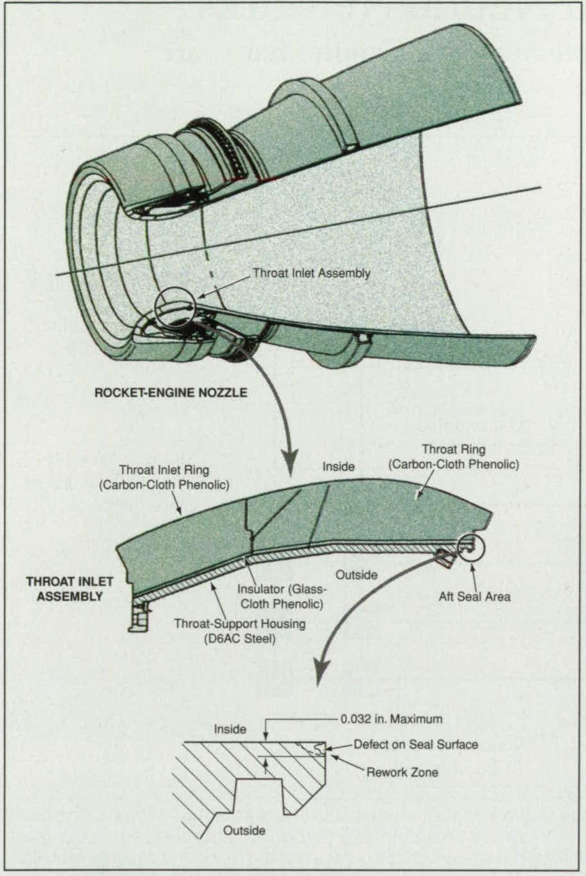


Figure 1. **Material Containing a Defect** must be removed from the inside edge of the seal surface. The depth of removal must not exceed 0.032 in. (0.81 mm).

In addition to providing better control over the material-removal process, this tooling saves time and relieves technicians of the tedious and fatiguing filing task. Unlike in manual filing, the technician need not exert major force while stroking. For a typical housing, manual filing takes about ten hours. With the present grinding tool and fixtures, the process can be completed in less than one hour.

This work was done by Ronald B. Montgomery, M. Bryan Ream, and Brent A. Mecham of Thiokol Corp. for **Marshall Space Flight Center.**

MFS-31326

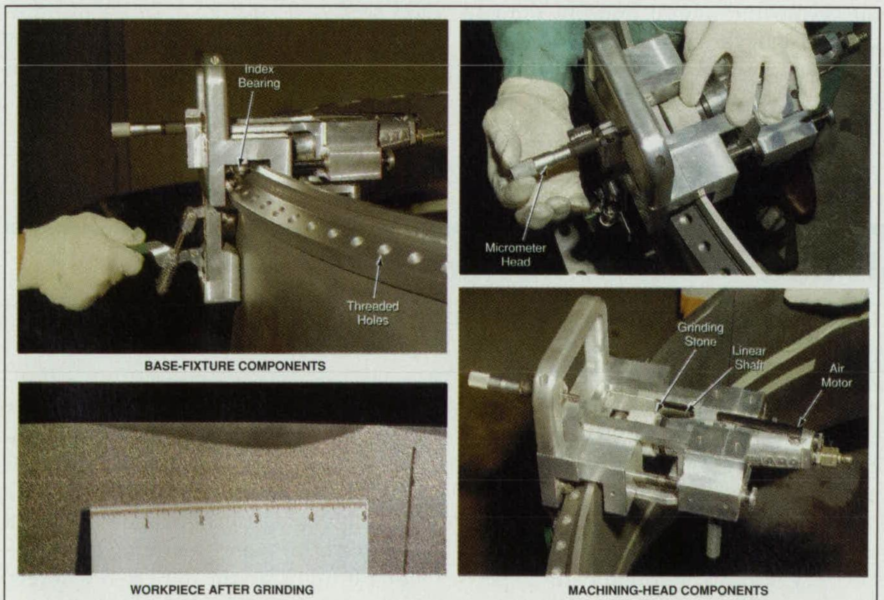


Figure 2. The **Grinding Tool and Fixtures** make the material-removal process faster, easier, and more controllable, in comparison with a formerly used manual filing process.

Information Sciences

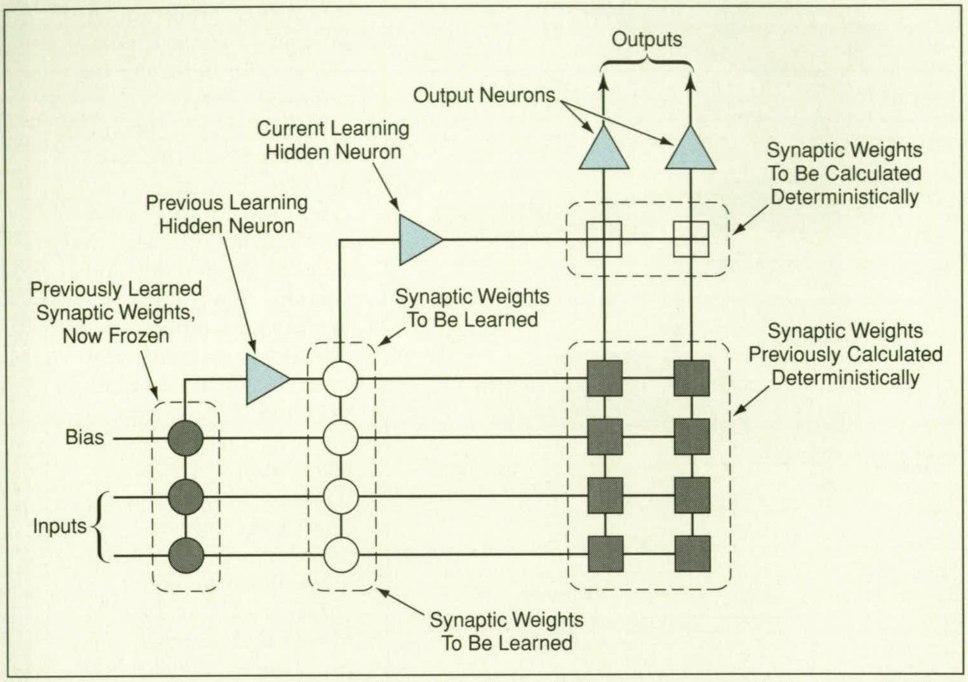
Cascade Error-Projection Learning in Neural Networks

This algorithm involves fewer iterations and can be implemented in simpler hardware.

NASA's Jet Propulsion Laboratory, Pasadena, California

Cascade error projection (CEP) is an improved learning algorithm for artificial neural networks. CEP is reliable and suitable for efficient implementation in very-large-scale integrated (VLSI) circuitry. In comparison with other neural-network-learning algorithms, CEP involves fewer iterations and is more tolerant of low resolution in the quantization of synaptic weights; thus, CEP learns relatively quickly and the circuitry needed to implement it is relatively simple.

CEP incorporates a cascading-architecture feature (see figure) of a prior algorithm called "cascade correlation." CEP also incorporates an independent-learning-neural-layer feature from cascade back-propagation.



The **Architecture of Cascade Error Propagation** includes inputs, hidden neurons, and output neurons. The blank circles represent synaptic weights that are to be learned according to a perceptron approach, while the blank squares represent synaptic weights to be calculated deterministically. The shaded circles and squares represent synaptic weights that have been so learned and calculated previously and are now frozen.

In addition, CEP is built on a firm theoretical foundation that involves mathematical modeling of the learning process in terms of the abstract space of synaptic-connection weights. The "projection" aspect of CEP denotes an approach in which an error surface is projected onto the current hidden learning neuron and its synapses. The firm theoretical foundation is provided by a theorem that says, in essence, that as the learning hidden neural units are incorporated into the neural network sequentially in cascade, the resulting cascade of sequential subspaces ensures that the neural network converges on its learning objective.

This work was done by Tuan A. Duong of Caltech for NASA's Jet Propulsion Laboratory. For further information, access the Technical Support Package (TSP) ***free on-line at www.nasatech.com*** *under the Information Sciences category.*
NPO-19644

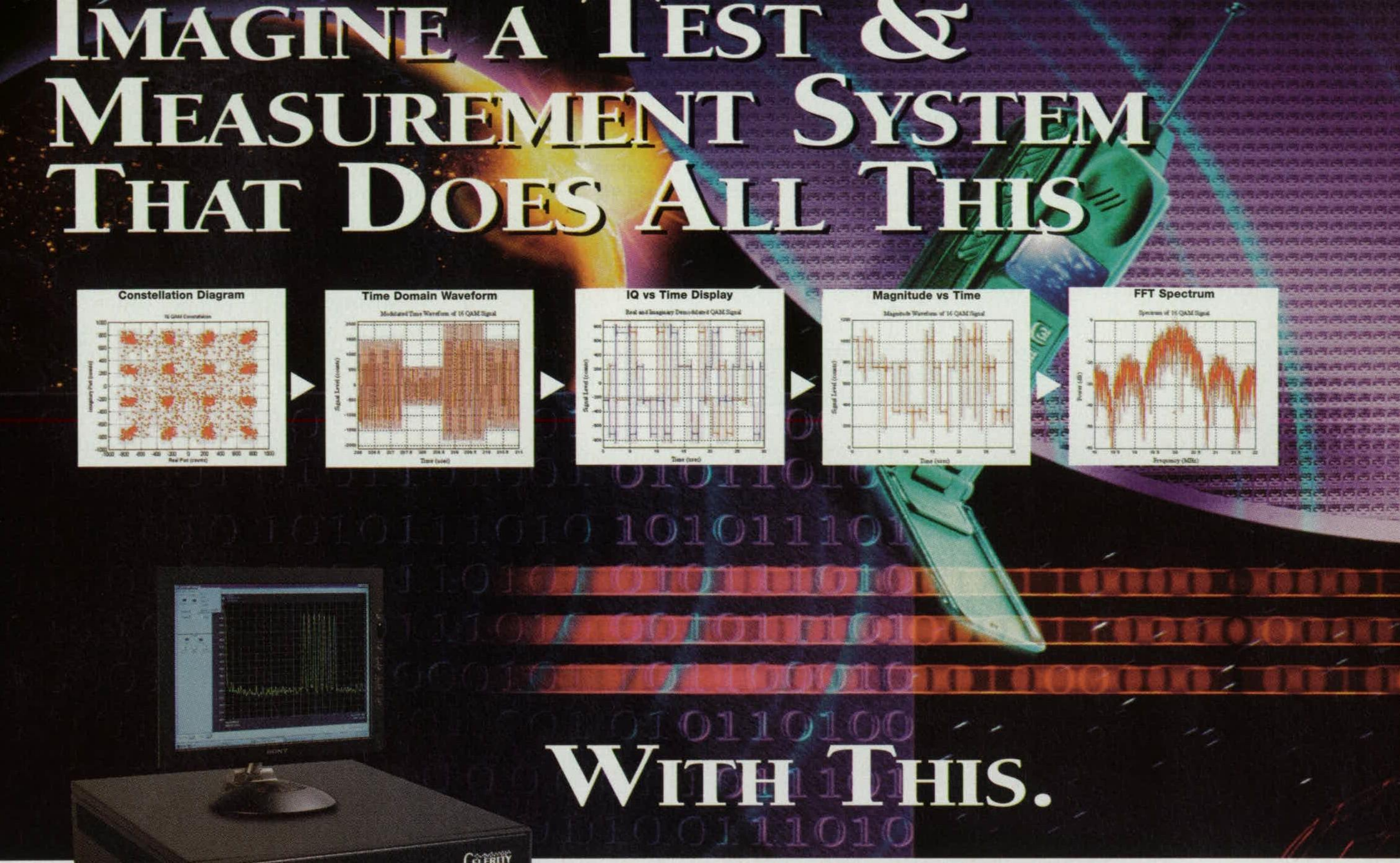
Expert System Controls and Monitors Thermal System

A symbolic controller recognizes malfunctions and takes corrective action.

Ames Research Center, Moffett Field, California

The Thermal Expert System (TEXSYS) computer program exerts real-time control over a complicated thermal-regulatory system that includes evaporators, condensers, a pump, valves, and sensors. TEXSYS observes differences between actual and expected conditions and analyzes differences to determine whether a given condition signifies a malfunction in a component or at the system level. It then takes corrective action (e.g., it commands the opening or closing of a valve).

A knowledge base of engineering expertise on the particular thermal-regulatory system is contained in an expert-system computer program called "core TEXSYS." TEXSYS was developed by adding core TEXSYS to conventional software for acquisition of data and for control, forming a hierarchical symbolic controller. The architecture of TEXSYS is layered, with the expert system at the top, the controlled hardware and conventional controlling hardware and software at the lowest two levels, and an intermediate layer that integrates the expert system with the lower levels (see figure).



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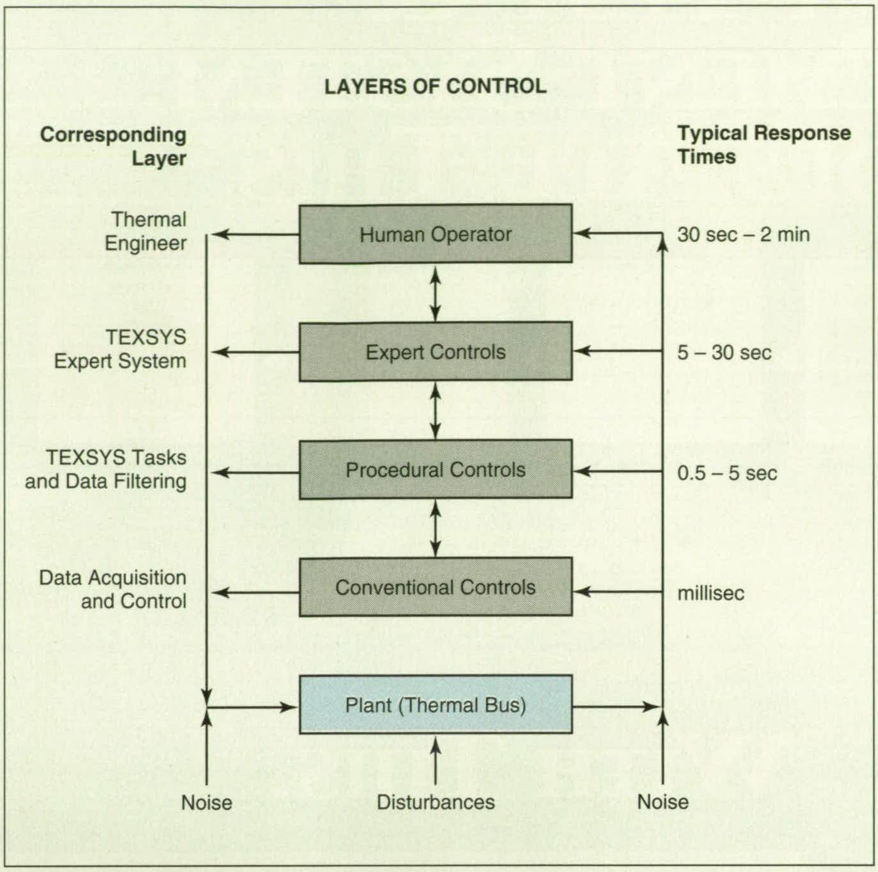


The **Symbolic Control Hierarchy Extends** from the hardware layer to the expert system at the top. The hardware is a thermal regulatory system (Carnot refrigerator).

The thermal regulatory system to be controlled includes a thermal bus that functions as a Carnot refrigerator, using anhydrous ammonia as the working fluid. A heat-acquisition branch absorbs heat from an external source, changing the working fluid from liquid to mixed liquid and vapor. The mixture is separated in a heat-transport branch by a centrifugal pitot pump, which sends vapor to condensers in a heat-rejection branch and liquid back to the heat-acquisition branch. A regulating valve on the downstream vapor line maintains a constant set-point pressure (and constant temperature, if the vapor is saturated), much like a relief valve. Once in normal operation, the thermal bus tends to balance itself, requiring control of the valve setting, pump power, and occasionally, the set point.

Real-time control requires response times of tens of seconds — 15 seconds during startup. To ensure fast response, data to be processed by TEXSYS are filtered so that only data on significant changes are entered; steady or slowly changing data, which would take an inordinate amount of time to consider, are eliminated. TEXSYS can identify all of the 7 known system-level faults and the 10 of 34 component-level faults that were chosen by thermal engineers as most interesting or representative.

So that TEXSYS can accept changes in hardware, a library of behaviors of generic components (how valves, pipes, and pumps function) was incorporated and separated from information on the behavior of the specific thermal bus. When thermal bus hardware changes, a new mathematical model is created in TEXSYS by choosing components from this library and connecting them as in the schematic diagram of the hardware. New data from the intermediate or integration layer of TEXSYS are placed into the model at sensor locations, then processed both by active values (across connections) and by rules (across components). The insertion of a datum at a given location in the model may then result in a chain of inferences about the behavior of the system.

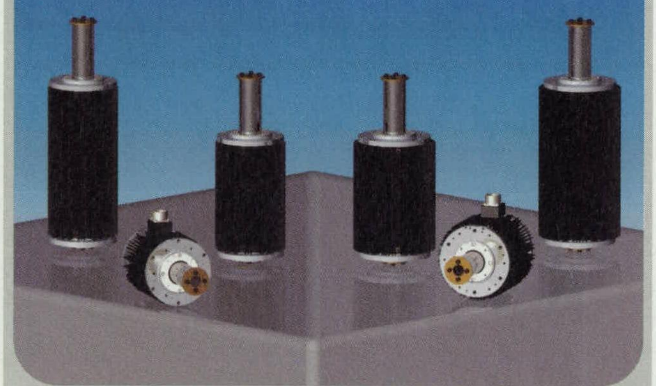
This work was done by W. Erickson, B. J. Glass, R. Owens, and M. S. Rudokas of **Ames Research Center**, *R. Levinson of Recom Software, Inc., and J. Nienart of Sterling Software. For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Information Sciences category.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center; (650) 604-5104. Refer to ARC-13166.

Motion Control Tech Briefs

Tubular Linear Motors: On the Growth Curve

Aerospace, electronics, and medical applications can benefit from the rise of this advanced motor technology.



The expanded tubular linear motor family from California Linear Devices.

As technology evolves, the number of viable options for producing linear motion continues to increase. In response to the rising sentiment to replace hydraulics, pneumatics, ball screws and other electromechanical motion "solutions" on the modern production floor, a wide range of direct-drive technologies is gaining popularity.

Direct-drive linear motors offer a highly attractive alternative to the fluids of hydraulics, lubricated exhaust of pneumatics, and the wear and subsequent backlash associated with traditional electromechanical devices including ball screws, cams, belts and pulleys. These traditional, non-direct-drive methods do not have magnets. As a result, they must rely on mechanical means, compressed air, or hydraulic fluids under pressure to achieve motion and force. When high precision and accuracy are required, direct-drive motors offer far superior performance over these technologies. The main objection to the former, in the past, was always overall cost and difficulty of integration.

Recently, two factors have emerged that have caused many motion-system designers, and cost-conscious buyers, to take notice of direct-drive linear motors. The first is that the magnets that are fundamental to their operation are now readily available at considerably lower prices than in the past. And with the improvements made in digital control technology, these high-performance devices can be brought under a measure of control that takes full advantage of their speed, accuracy, and sensitivity.

The market for direct-drive linear motors and drives in North America is experiencing tremendous growth. The primary reason behind this is the overall prevailing sense of urgency in the factory automation and instrumentation communities about increasing machine throughput and improving manufacturing efficiencies.

The inherent simplicity of direct-drive motors leads to a number of significant advantages over traditional approaches to linear motion and motion control. Since there are no gear boxes, ball screws, pulleys, or mechanical transmissions to deal with, both failure potential and maintenance requirements are dramatically reduced. The decrease in the number of moving, wearing parts means longer cycle life and less downtime.

The performance benefits are also substantial. Since feedback resolution is high, direct-drive systems can be counted on to deliver superior repeatability and stiff true position by eliminating backlash and the mechanical transmission. Overall servo performance is also much better. All of these factors add up to lower cost, higher throughput, and greater productivity for a wide range of production applications.

Enter Tubular Linear Motors

A hot new product that takes great advantage of direct-drive technology is the permanent-magnet tubular linear motor. With their high force capabilities, tubular linear motors offer motion-system designers a great opportunity to replace hydraulic and pneumatic actuators with direct-drive linear servo motor technology.

Unlike other linear motors, tubular linear motors have integrated built-in bearing systems, a huge advantage. They are able to deliver high force and rapid movement from compact, rugged packages. Maximum forces are possible to 1500 lbs. and beyond, and maximum speeds can exceed 100 in./sec.

Whether used for rotary or linear motion, magnetics is the key to direct-drive technology. With direct-drive motors, a magnetic field provides the interaction between a stationary part and a moving part. This characteristic provides a very reliable and accurate method for achieving force and motion control.

The magnets are the reason for the superior performance of these devices. Neodymium magnets make it possible to achieve high force with low inertia. The result is a very cost-effective method for achieving precise linear motion.

This cost breakthrough allows the system designer to use the magnets as the moving member, eliminating the need for expensive cabling trays. The coils become the stationary part. Additionally there are now a number of attractive

cooling options for designers of tubular linear motors, including jackets, water, or forced air. You no longer need a moving water system to handle this critical function.

The importance of the price reduction of the magnetic material is difficult to overstate. Just two years ago, the magnets for a typical tubular linear motor cost as much as $32 apiece, and they are now available at around $8—one quarter as much, and in some cases even less than that.

The recent advances in magnetics have yielded an extremely responsive motion system. In the past, however, motion-system designers have been faced with the dilemma of how to bring this technology under control. The exceptional responsiveness of tubular linear motors requires the speed, power, and precise control only recently available in the newer generations of drives and controllers. Servo drives, which are now far more advanced and readily available, have rendered the goal of harnessing the responsiveness of tubular linear motors a reality.

The hyper-responsiveness of the typical permanent-magnet brushless tubular linear motor is attributable to its magnetic geometry, which creates a force-to-mass ratio greater than 75 g. For example, you can produce 750 lbs. of force on a ten-pound permanent-magnet shaft. You need a high-speed control system to make this work and maintain good precision. That capability is now readily available in a variety of formats and servo-system architectures.

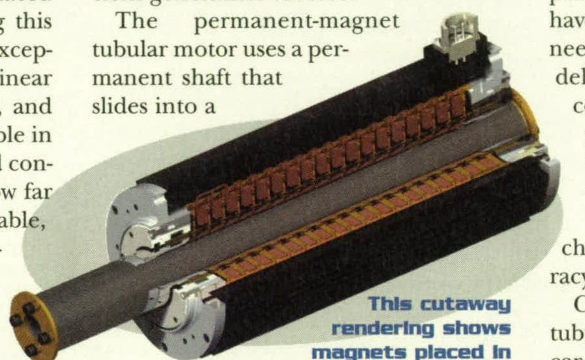
Drive electronics, including the motion controller, amplifier, feedback method, and control algorithm, play a major role in the performance of linear motion systems. With the advances in digital technology, rapid improvements have been made in controllability.

Because of the very low inertia of the moving member relative to the high forces of these devices, previously only the fastest servo amplifiers had been able to harness them. Now, off-the-shelf standard drives and brushless servo controllers are capable of driving them. These motors do not need custom control systems and drives. Obviously, too, higher-performance drives make the system more cost-effective overall.

These motors do not need custom control systems and drives.. Additionally, the flexibility of feedback devices enables tubular linear motors to fit into system architecture using position and/or force feedback. These motors can accommodate both position and force control, and can utilize both resolver- and encoder-based control. This versatility gives them great potential for numerous high-performance automated applications.

Permanent-magnet brushless tubular linear motors offer a superior method for capturing and maximizing the inherent advantages of direct-drive technology. With a single moving part and an integral bearing system, these motors can accelerate quickly to high velocities, even when handling heavy loads. Their elegant yet simple design provides robust, reliable operation and longer cycle life. More importantly, the tubular configuration results in a highly efficient generation of force.

The permanent-magnet tubular motor uses a permanent shaft that slides into a stator assembly that contains electromechanical coils. The stator's length and diameter set the force level, while the shaft length determines the stroke. Linear motion is controlled directly through a precision feedback device, which relays detailed position information to a motion controller. There is no backlash or compressibility to compromise position accuracy, as occurs with ball or jack screw linear devices.



This cutaway rendering shows magnets placed in alternating polarities down the length of the motor shaft.

The simplicity of permanent-magnet brushless tubular linear motors carries benefits for just about any factory motion application: in addition to the one moving part, they have just two wearing parts; an encoder can be mounted directly to the motor; they are compact in size; no supporting mechanical systems, pumps, or tanks are necessary; and they are environmentally friendly, with no oil or hydraulic fluids, and quiet in operation.

In addition to those benefits, these motors have numerous inherent characteristics that result in a lower life-cycle cost:

- Their simple design costs less to integrate and install;
- Standard feedback devices can be used;
- There are fewer maintenance requirements; and
- No environmental control activities are necessary.

Tubular vs. the Competition

Other direct-drive linear technologies, including flat linear motors, offer excellent accuracy, resolution, and speed. The downside is that they offer these benefits at a premium price. Additionally, many competitive approaches require an external linear bearing system to support and position the moving member in relationship to the magnets. Such a bearing system can cost as much as the motor.

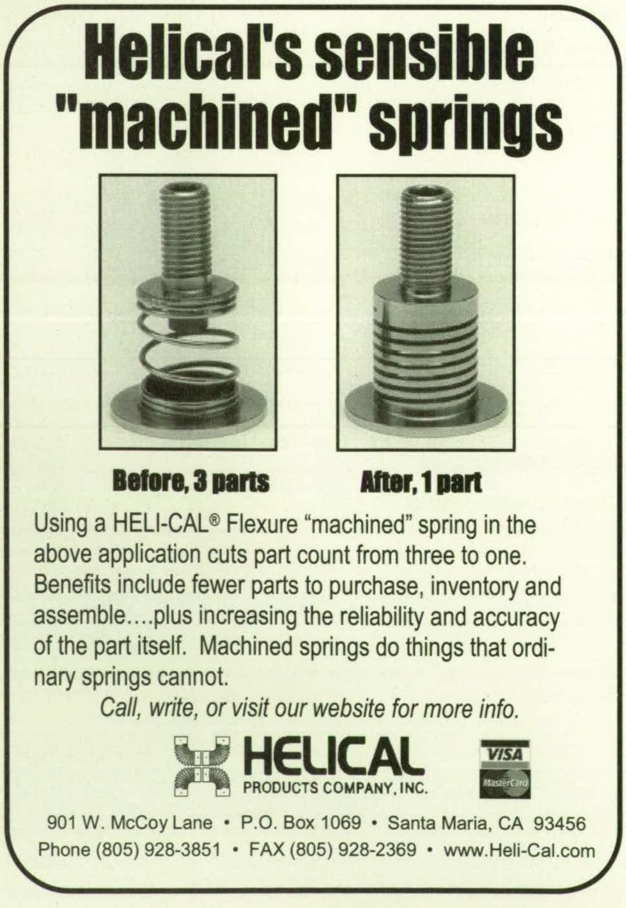
Permanent-magnet brushless motors have taken the leadership of the direct-drive linear motor market. There are a number of reasons why. First, smaller packages are achievable: the magnets have a low profile, and no flux coils are needed. Permanent-magnet motors also deliver a higher continuous force per coil area. And they use standard three-phase brushless commutation, while linear induction motors need drives with amplitude and frequency control. Best of all, their simpler mechanical design ensures higher accuracy and greater durability.

California Linear Devices' (CLD) tubular brushless direct-drive-based linear motor technology is an excellent fit for a broad range of industrial applications. CLD's design incorporates a DC stator and rare-earth neodymium-iron-boron permanent magnets around the periphery of the shaft. As with a conventional linear actuator, the rotor lies flat, and is then formed into a tube. The distinct advantage this approach provides is that the electromagnetic interaction takes place over the 360-degree surface area of the shaft, resulting in a high force-to-volume linear motion solution.

CLD offers six different standard models, and integration with most popular drives and feedback devices. Peak loads range from 100 to 1500 lbs., with a continuous rating of about 50 percent, depending on duty cycle and the cooling option utilized. Strokes up to 18 inches are available. The CLD system maintains a force accuracy of 1 percent or better at 340 lbs. of force, delivers speeds up to 50 in./sec., and maintains position accuracy to 0.001 inch. Tubular technology integrates easily with sensors for all types of popular drive architectures. Easily integrated, the CLD motor is qualified with all of the major drive manufacturers.

Applications

The high speeds and forces attainable with tubular linear motors represent a tremendous upgrade compared to those afforded by cam and crank-driven devices. Machines such as weaving and tuft-



ing systems can now utilize servo control. The hours of setup time formerly wasted on changing cams and adjusting connecting rods is now replaced with the push of a button.

There are a number of prime targets for replacement with tubular linear motors, including:

- High-speed packaging, bottling, and canning: CLD's tubular linear motor provides increased programmability, reduces setup time, and improves flexibility, allowing a wider variety of products to be packaged on a single machine–naturally, increasing the machine's value;
- High-speed printing and stamping: Tubular linear motors improve accuracy to increase resolution, while also increasing machine throughput;
- Garment production (sewing, weaving, and tufting): The mechanical setups of belts and cams are eliminated; linear servo motors allow all-digital setups, changeovers, and control, and since the user programs the motion profile, he doesn't have to idle the machine to change the setup manually–just call up the desired profile, flip the switch, and go;
- Injection molding: Tubular linear motors improve accuracy, which is critical in this application;
- Vibratory part feeders and mixers: The reduced number of moving parts and rugged construction of the CLD motor provide increased reliability for these high-stress applications;
- Fastback conveyors: Tubular linear motors give the user the power to achieve great accuracy and gain total control of his move profiles. This gives him the flexibility to easily account for conveyor oscillation, and the ability to program his profiles to accommodate different materials.

In addition to giving the user precise motion control, tubular linear motors offer exceptional performance for applications that require varying controlled force or pressure:

- Resistance welding: The ability of tubular linear motors to provide both positional and force control is a huge advantage for welding applications. After beginning in position mode, pressure can be applied by the weld electrode using digitally controlled force. Then, switching back to position control allows the weld nugget to grow;
- Material testing: Tubular linear motors allow both dynamic and static testing;
- Precise fluid pumping: Tubular motors' programmability allows the varying of move profiles to reduce the possibility of pump cavitation;
- High-speed crimping: Servo linear control enables precise probe positioning.

For applications requiring clean operation, tubular linear motors eliminate contamination by hydraulic fluid and the airborne lubricant contained in the exhaust from pneumatic operation. Industries that can profit from the cleaner operation afforded by tubular linear motors include consumer electronics manufacturing, semiconductor manufacturing, clean-room manufacturing, and medical manufacturing and processes.

Aerospace is also a field that is well suited for tubular linear motors. With their ability to achieve high redundancy, high force-to-weight ratios, exceptional responsiveness, and durability, it is only a matter of time before they are widely utilized in aerospace and military applications.

The high-performance tubular linear motor is now ready for widespread practical application through the availability of lower-cost magnets and higher-speed electronic control. It is now well equipped to answer the mandate to supplant hydraulics and pneumatics on the factory floor.

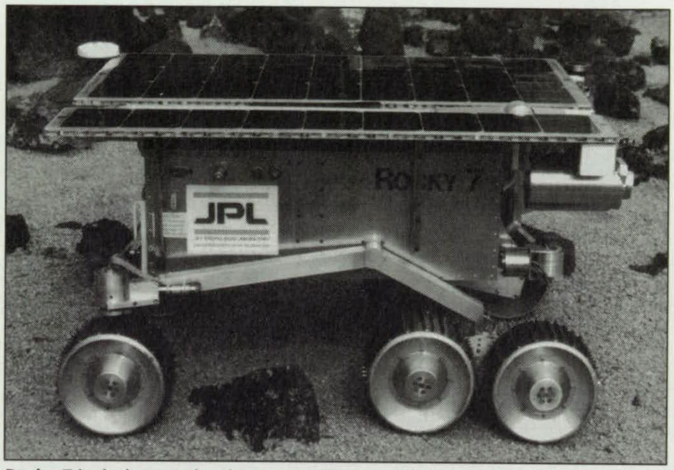
For more information, contact the author of this article, Gary Schultze, electrical engineer, at California Linear Devices, 2236 Rutherford Rd., #119, Carlsbad, CA 92008; 760-603-8026; fax: 760-603-0049; www.calinear.com.

Estimation of Wheel-Contact State of a Robotic Vehicle

An odometric estimate of position can be made more accurate.

NASA's Jet Propulsion Laboratory, Pasadena, California

A method of estimating the state of contact between (1) the wheels of a robotic vehicle equipped with a rocker-bogey suspension and (2) the ground has been devised. The contact-state information is used to estimate the position of the vehicle with an accuracy greater than that achievable by simple odometry and inertial sensing when the vehicle moves over undulating or bumpy terrain under conditions in which processing of visual odometry information is infeasible or undesirable. The contact-state information can also be used to increase understanding of those aspects of design and operation of the vehicle that affect stability and traction, as affected by the configuration of the rocker-bogey and steering mechanisms. The method in its original form is meant to be applied to Rocky-7 (see figure) — a "rover"-type vehicle used in research on robotic-vehicle concepts for the exploration of Mars. The method is also potentially applicable to terrestrial robotic vehicles that could be used in field operations in agriculture, mining, and other industries.



Rocky-7 includes a rocker-bogey suspension with two steerable front wheels. The present method provides for estimation of the state of wheel/ground contact on the basis of sensor readings and the highly nonlinear kinematics of the rocker/bogey suspension.

In this method, the forward kinematics of the vehicle (proceeding from the vehicle frame to the wheel/ground contact points) are embedded within a constraint that is treated as a measurement. The forward kinematic chain velocity for each wheel includes a component defined by the sequence of links that join the vehicle frame to the wheel/ground contact point, plus a component given by the slip between the wheel and the ground. An important element of the method is the notion of a slip measurement or constraint that defines the six-degree-of-freedom (6-dof) motion of the contact frame on the wheel, relative to the ground. The slip is a function of the vehicle configuration, the 6-dof vehicle velocity, the location of the wheel/ground contact points, and the rates of rotation of the joints along the various kinematic chains.

The slip can be decomposed into a deterministic component and a component that is known in a statistical sense only. The deterministic component of the slip is used to capture the effects of a known steering action; for example, a known rotational slip about the vertical is always present at each wheel to accommodate the yaw motion of the vehicle during a turn. Also, some transverse slip is introduced because of the nature of the nonsteered bogey wheels. These deterministic slips are easily calculable for steered motions on flat ground, and those calculated for flat ground are used as approximations for those on nonflat ground. Other slip constraints can be derived from experiments. Slips that are modeled statistically include those attributable to wheel-ground interactions and to curvature of the terrain.

The state-estimation algorithm of this method utilizes an extended Kalman filter to fuse data from multiple sensors aboard the vehicle (e.g., a gyroscope, a Sun sensor, and accelerometers) while taking account of the kinematics of the rocker-bogey suspension and steering. In addition to the kinematic elements described above, the extended Kalman filter incorporates process models of attitude, translation, gyroscope bias, plus observation models for the gyroscope, Sun sensor, and accelerometer. The highly nonlinear kinematics of the rocker-bogey suspension and the wheel/ground contact points are incorporated into the filter via the slip constraint. The algorithm exploits the ability of the Kalman filter to perform the appropriate least-squares averaging of the action of each kinematic chain in the vehicle.

This work was done by J. Balaram of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line*** *at www.nasatech.com under the Mechanics category. NPO-20960*

Advanced, Lightweight, Low-Power-Consumption Actuator Brake

This brake features a modular, fault-tolerant design.

Lyndon B. Johnson Space Center, Houston, Texas

An advanced, lightweight, low-power consumption brake has been developed to satisfy NASA's special requirements for use on actuators during spaceflight. This brake can increase the stopping, holding, and parking ability of a spacecraft while reducing its electrical power consumption. Two notable strengths of the design of this brake are modularity and fault tolerance. The use of brakes like this one can be expected to increase performance measures and safety margins in terrestrial as well as outer-space applications.

Brakes of this type are used in outer space or on Earth to stop, hold, or park a moving vehicle that is being driven by electromechanical devices. In spaceflight, brakes must be lightweight, exhibit short closing times, and conform to the geometries of pre-existing actuator structures. The principal issue in designing brakes for spacecraft is excessive power consumption, which is particularly costly

Parameter	Standard Practice	NASA Design
Torque ÷ Weight, lb-ft/lb	1.6	5.2
Volume, in.^{3}	28.5	12
Response Time, ms	40	20
Power Consumption, W	0.5	0.012 (Conservative Estimate)

Key Parameters of the NASA design are compared with those of a design according to standard practice.

under circumstances in which resources are already at a premium and the loss of resources could cost time or jeopardize human lives. Although in some respects the situation is less critical on Earth, lives are nonetheless frequently lost when vehicle brakes fail. An advanced electromechanical braking system that satisfies the requirements for spacecraft and that increases the braking ability of Earth vehicles would surely prove beneficial to the government and to commerce.

When NASA assigned the task of designing an advanced braking system that could reduce the cost of spaceflight, it asked not only that the essential requirements pertaining to spaceflight (low power consumption and minimal thermal effects) be satisfied but that they be satisfied in a manner surpassing previous designs while reducing power consumption to 1/100 of a baseline level. Some of the benefits of the NASA design, relative to a design according to standard practice, are illustrated in the table. The modularity of design is another benefit: two or more modules can be included in a single braking system, so that if one brake fails the other brake(s) will continue to operate. Such redundancy creates a level of fault tolerance unequalled in previous space-deployed brake designs.

Brakes like this one could be used not only in outer space but also on Earth in applications in which multiple actuators operate at moderate to high temperatures, design goals include minimization of weight and power consumption, and there is a need for the insurance added by redundancy. Such brakes would be suitable for use with servo-actuators, especially in robots, wheeled exploratory vehicles, antenna-deployment mechanisms, and power tools.

This work was done by Delbert Tesar, Hau Nguyen-Phuc Pham, Derek Black, William F. Weldon, Richard Hooper, and Michael James Meaney of the University of Texas at Austin for **Johnson Space Center**. *MSC-22867*

Controlling Speed of a Robotic Vehicle Over Rough Terrain

Speed is commanded according to vehicle dynamics and stereoscopically measured terrain-height variations.

NASA's Jet Propulsion Laboratory, Pasadena, California

A method of computing the speed at which to command an autonomous robotic vehicle to travel over rough terrain has been devised. The method amounts to a robotic implementation of the practice in which, during approach to a visibly rough surface, a human driver intuitively reduces the speed of a car or truck to prevent excessive bounce, damage to the vehicle, or loss of control.

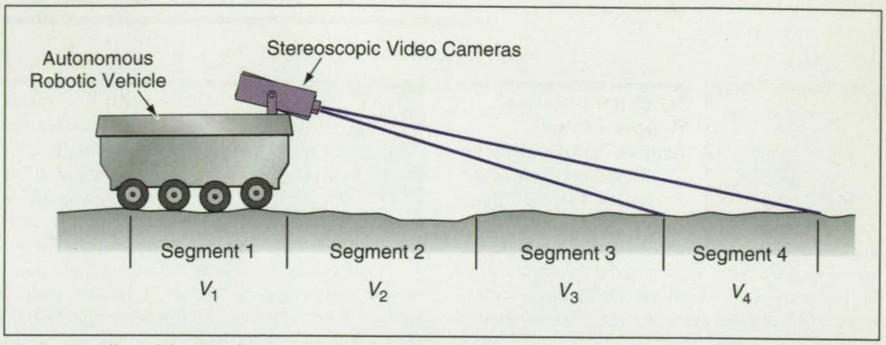
The method is applicable to a robotic vehicle equipped with (1) a stereoscopic machine-vision system that generates data equivalent to a topographical map of the terrain in the vicinity of the vehicle, (2) an onboard navigation system that computes the planned path of the vehicle across the terrain, and (3) a speed-control system. In this method, the process for generating a speed command begins with utilization of the topographical and planned-path data to compute the relative surface height as a function of distance along the planned tire tracks immediately ahead of the vehicle. The roughness of the surface

along each tire track is quantified in terms of the derivatives (particularly the second derivative) of surface height with respect to distance. To suppress the additional noise that would otherwise be generated by differentiation of noisy height data, the height-vs.-distance data are fitted piecewise cubic spline polynomial curves, the parameters of which give the required derivatives directly.

The maximum allowable speed, for the purpose of generating a velocity command, is deemed to be the speed that results in a maximum allowable bounce (as quantified in terms of vertical acceleration). To calculate vertical acceleration, the dynamics of the vehicle at each tire are represented by a mathematical model in which a spring-and-damper combination (representing the tire) is in series with another spring-and-damper combination (representing the suspension mechanism) that supports a rigid mass equal to a portion of the mass of the vehicle. Analysis of this model leads to a quadratic equation for the maximum allowable speed as a function of the maximum allowable vertical acceleration and of "road forcing" terms that contain the second derivative of the surface height. The solution of this equation for each position along a tire track yields the maximum allowable speed for that position.

Of course, it is necessary to (1) decelerate the vehicle to the maximum allowable speed for a given rough spot at least some short time before the vehicle reaches that spot, and (2) keep the speed low until the vehicle has cleared the rough spot. One strategy to accomplish this involves (1) maintaining a sequence of allowable speeds computed for nonoverlapping segments of the vehicle path immediately ahead and (2) commanding, at any given time, a speed that is the minimum of these allowable speeds. For example, suppose that four maximum-speed values ($V1$ through $V4$) are sufficient and that they pertain to segments of the path from the rear wheels to the stopping distance in front (see figure). As the vehicle moves forward, the current value of $V1$ is dropped from the sequence, the current values of $V2$ through $V4$ are assigned to $V1$ through $V3$, respectively, and a new maximum speed $V4$ is computed for the new fourth path segment coming into view.

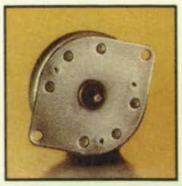
This work was done by Kenneth D. Owens of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Mechanics category. NPO-20762*



Maximum Allowable Speeds are calculated for four path segments on the basis of terrain-height variations computed from stereoscopic images of the terrain ahead. At any given time, the commanded speed of the vehicle along the path is the minimum of $V1$ through $V4$.

For More Information Circle No. 657

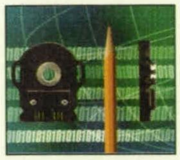
NEW PRODUCTS



Permanent-Magnet Stepper Motor

Thomson Airpax Mechatronics, Cheshire, CT, introduces the Series 44M100D high-torque permanent-magnet stepper motor. The company says the motor, with its 44-mm depth, was designed for limited space applications. The motor has a step angle of 3.6 degrees and 100 steps per revolution. It is 12 mm in length. Available in a bipolar version only, the device produces 30 mNm (4.25 oz.-in.) pull-out torque at 150 pps, when driven with a chopper drive. Thomson recommends it for electronic component delivery systems and precision testing instrumentation, as well as for medical test.

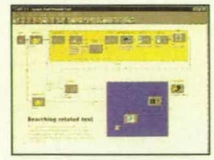
For More Information Circle No. 765



Encoder with Brushless Commutation Outputs

Renco Encoders, Goleta, CA, makes available the RCML 15, which combines brushless motor commutation pulses and an incremental position feedback in a low-profile single optical encoder 0.350 in. in height suited for use where space is critical. The device features Renco's patented slide-gap mechanism that the company says eases installation and maximizes performance. A built-in servo groove allows a ±20 degree rotation of the encoder to align the commutation tracks with the motor poles. The RCML is available with resolutions up to 2048 lines, and provides commutation for 4-, 6-, or 8-pole brushless motors.

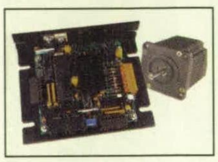
For More Information Circle No. 766



Programming Software for Machine Vision

Coreco Imaging, Bedford, MA, releases WiT 7.0, which it calls an enhanced version of its visual programming software for industrial and scientific machine vision. The company says that this version features a faster scheduler for quicker processing of algorithms, new memory and control operators for easier program design, and improved subparagraph management for faster development. WiT 7.0 also now includes the WiT Pro Toolkit bundled free of charge, adding a new C code generator that allows visual programs to be converted to structured C code.

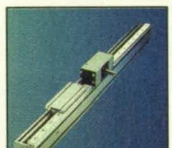
For More Information Circle No. 767



Microstepping Motor Driver

Advanced Micro Systems, Nashua, NH, describes its DCB-261 as a microstepping bipolar chopper-driver with an intelligent controller for operating small stepping motors. The device utilizes a chopper drive circuit with a 20-kHz chopping rate. The voltage range is from 24 to 40 VDC, and the output current is up to 1.2 A per phase. A 4-A/phase model is also available. On-board intelligent control, with more than 30 motion commands, provides step and direction signals to the driver to produce step rates in excess of 20,000 per second at various microstep resolutions.

For More Information Circle No. 768



Linear Drive Module

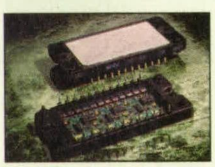
The HLE-Z linear drive module from Parker Hannifin's Daedal Division, Irwin, PA, can quickly and accurately position large payloads over very long travels, according to the company. A standard unit can transport payloads of as much as 600 kilograms over distances up to 50 meters. It can offer travel velocities to 5 meters per second, and repeatedly position within ±0.01 mm. Parker says the HLE-Z features a "Par-Trac" drive system that utilizes a timing-belt drive mechanism. This design permits an extended series of teeth to be fully engaged, the company says, providing optimum traction force and high positional repeatability.

For More Information Circle No. 769

Direct Drive Rotary Stage

Bayside Motion Group, Port Washington, NY, introduces a new direct drive rotary stage that it says has several advantages over traditional worm-gear-driven stages. Bayside calls the elimination of the worm gearing the key to reducing wear with zero backlash and exhibiting near-frictionless motion. Bayside says the stage's high positioning accuracy, solely based on its encoder, provides repeatability within ±2 encoder counts, with resolutions ranging to 0.5 arcsecond. The company recommends the direct drive rotary stage for applications in the semiconductor, robotics, assembly, pharmaceutical, packaging, medical equipment, and electronic assembly industries.

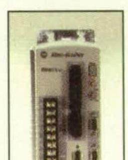
For More Information Circle No. 770



3-Phase Control for Motors

Apex Microtechnology, Tucson, AZ, offers the EB01, EB02, and EB03, the first three model releases in a new "Easy Bridge" motion control product family. The devices provide a drive "bridge" between a motor and a DSP/digital signal. By using one EB in conjunction with a single DSP device, a designer can obtain three-phase control for brushless DC, stepper, and AC motors. Each EB consists of three independent IGBT or FET half-bridges with drivers. Electrical performance features include output current of up to 20 A, with 40 A peak pulses, and compatibility with PWM frequencies of up to 50 kHz.

For More Information Circle No. 771



Motion Control and Drive Package

Rockwell Automation, Mequon, WI, makes available the Allen-Bradley Ultra5000 intelligent positioning drive for single-axis motion applications. This drive integrates a high-speed digital signal processor (DSP), standard C programming language interface, and on-board input/output and communication capabilities. The Ultra5000's DSP is 32-bit, and its application code is compiled rather than interpreted to streamline the user program's execution, according to the company. The motion controller's position loop is updated 2000 times a second, reducing the Ultra5000's reaction time.

For More Information Circle No. 772

Stepper/Servo Motor Brakes

Electroid Co., Springfield, NJ, says that its Models FEB, RFEB, and SSB front-end brakes were specifically designed for a wide variety of stepper/servo motor applications. All are power-off, or failsafe, units that mount to the front end of a stepper or servo motor for added safety or for holding the load in place. The company says the brakes have fast response and low backlash (zero backlash on the SSB). Twenty-four and 90 VDC are standard, and they are available in two standard sizes to fit NEMA-23 and NEMA-24 frames (the SSB model is also available in NEMA-42).

For More Information Circle No. 773

Digital Motor Controls

Baldor Electric Co., Fort Smith, AR, introduces a new line of digital "soft-start" motor controls featuring adaptable soft-starting techniques. These controls are available with output ratings of 9 to 900 A for motors from three to 700 HP, and feature a 32-character plain-English display keypad. The operator enters operating parameters on the keypad and the control software automatically sets to the application. The soft-start controls also have the capability to adjust the output voltage to the motor, which allows the motor to run more efficiently, saving energy.

For More Information Circle No. 774

Motor Server Block Controller

Douloi Automation, Santa Clara, CA, describes its new motion server block controller as combining multiple communication channels, industrial networking, optoisolated power I/O, and terminal block interconnect with a multiaxis mixed motor-type motion controller with advanced programming capabilities. The controller can control up to 10 motors in independent coordinated groups simultaneously. As many as 12 high-speed, real-time on-board application programs can run concurrently. A 128-MHz 32-bit processor with 80-bit floating-point hardware provides the power for multiaxis coordination and kinematic models.

For More Information Circle No. 775

Handheld Motion Terminals

Two Technologies, Horsham, PA, announces the ProMotion, the most recent addition to its family of handheld terminals. Designed for motion control, the ProMotion has a double-pole three-position (off/on/off) "Liveman" switch plus a double-pole emergency stop. The three-position design of the switch provides a closed circuit when depressed to a midpoint. If the switch is released or depressed fully, the switch circuit is opened. The mushroom-cap emergency stop switch is easily activated with a push-turn motion. ProMotion also features a large-screen LCD display with both text and graphics capabilities.

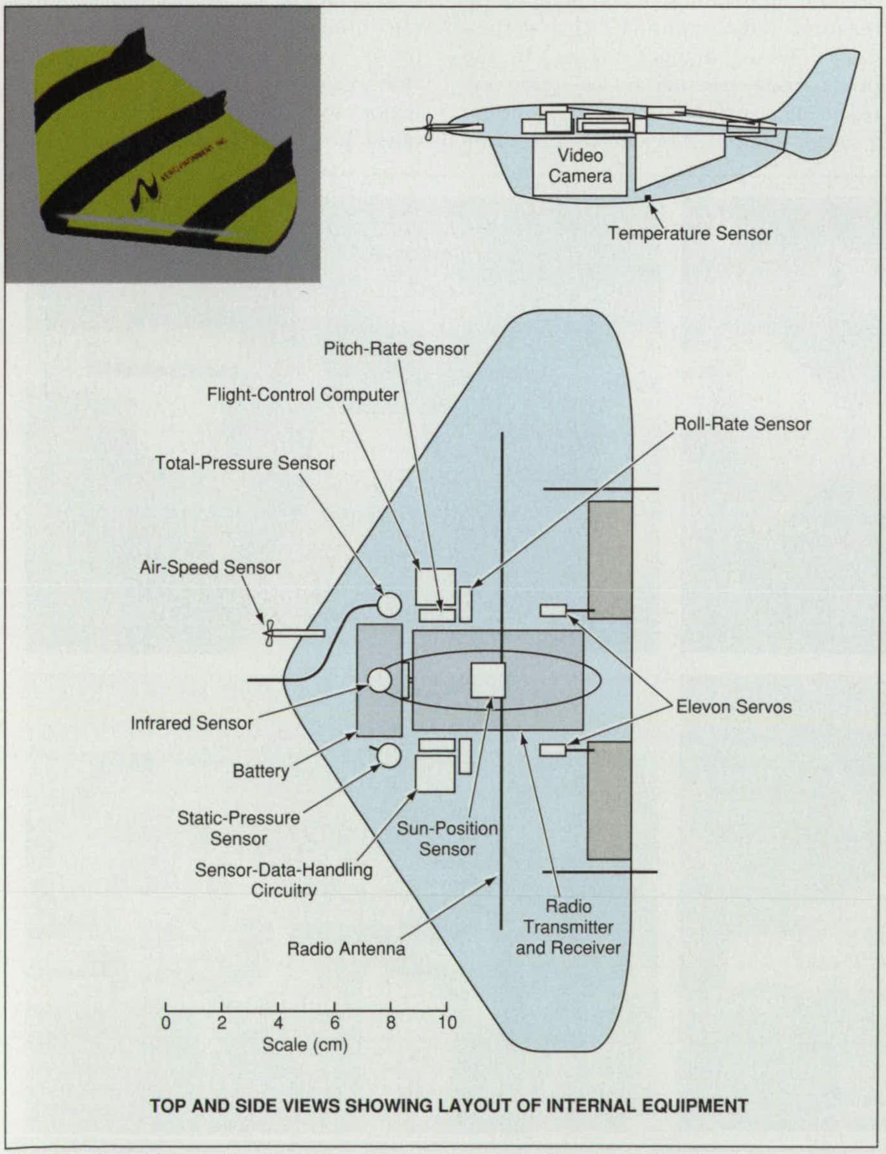
For More Information Circle No. 776

Biomorphic Gliders

Miniature robotic microflyers would gather scientific data to enable reconnaissance missions and deploy payloads on landing.

NASA's Jet Propulsion Laboratory, Pasadena, California

Biomorphic gliders are small robotic microflyers proposed for use in scientific exploration of planetary atmospheres and terrains that capture some key features of insect and bird flight. Biomorphic gliders as biomorphic flight systems are a subset of biomorphic explorers. The multidisciplinary system concept of "Biomorphic Explorers" represents small, dedicated, low-cost explorers that possess some of the key features of biological systems, not easily captured by conventional robotic systems. Such features particularly include versatile mobility, adaptive controls, bioinspired sensor mechanisms, biomorphic sensor fusion, biomorphic communications, biomorphic cooperative behavior, distributed operations, and biomorphic energy generation/conversion. Significant scientific and technological payoff at a low cost is realizable by using the potential offered by a large number of such cooperatively operating biomorphic explorer units in concert with the traditional exploration platforms such as the lander/rover, orbiter, etc., for example.



A **Biomorphic Glider** would carry miniaturized equipment for flight control, navigation, communication, and scientific observation/analysis.

Biomorphic Explorers and some concepts on biomorphic surface/subsurface systems have been described in several previous articles in *NASA Tech Briefs*, the most relevant being "Biomorphic Explorers" (NPO-20142), Vol. 22, No. 9, (September 1998), page 71; "Earthwormlike Exploratory Robots" (NPO-20266), Vol. 22, No. 6, (June 1998), page 11b; and "Insectile and Vermitorm Exploratory Robots" (NPO-20381), Vol. 23, No. 11, (November, 1999), page 61. Particularly, the biomorphic glider is a small, simple, low-cost system ideal for distributed measurements, reconnaissance, and wide-area dispersion of sensors and small experiments.

The key specifications/ features of a biomorphic glider include: mass of 100 to 500 g, payload fraction > 50 percent, large range of aerial mobility of 10 to 100 km, volume 300 to 5,000 cm^3, active flight control, solar navigation, soaring flight using atmospheric energy, cooperative mission using from 10 to 30 gliders providing coverage of area of about 100 × 100 km. The glider is particularly suitable for deployment in large numbers to perform reconnaissance over large areas. A typical biomorphic glider (see figure) would be equipped with sensors (meteorological instrumentation such as temperature, pressure, solar irradiance, and moisture sensor, etc., and/or miniature imagers for close-up imaging of the terrain) sensory-data-handling circuitry, flight-control actuators, control circuitry, and a radio transmitter and receiver. A biomorphic glider could navigate autonomously (e.g., by reference to the direction of the Sun). In a typical operation, multiple biomorphic gliders would be released from an aircraft or spacecraft in orbit/fly-by mode at an altitude of several kilometers and sent off to explore in different directions. Alternatively, they

could be launched from a Lander to inspect a number of sites and provide valuable information to allow selection of the best site for further probing by the rover. Biomorphic gliders could thereby enable enhanced data return for sample-return reconnaissance missions and provide a new capability for distributed measurements.

Additionally, the time aloft could be prolonged by controlling a biomorphic glider to utilize atmospheric energy in the same manner as that of soaring birds and particularly soaring insects that migrate large distances using such a capability.

During the flight of a biomorphic glider, the onboard instrumentation could gather data on the atmosphere and terrain. Images acquired by a small onboard video camera could contribute data for maps of the terrain, could be processed to identify targets for closer examination, and/or used to guide the glider to a landing at a chosen target site. A variety of surface instruments/experiments could be deployed by the glider on landing. The results of the analysis would be transmitted to a relay point, which could be, for example, a receiver aboard the lander or the aircraft/spacecraft from which the glider was released.

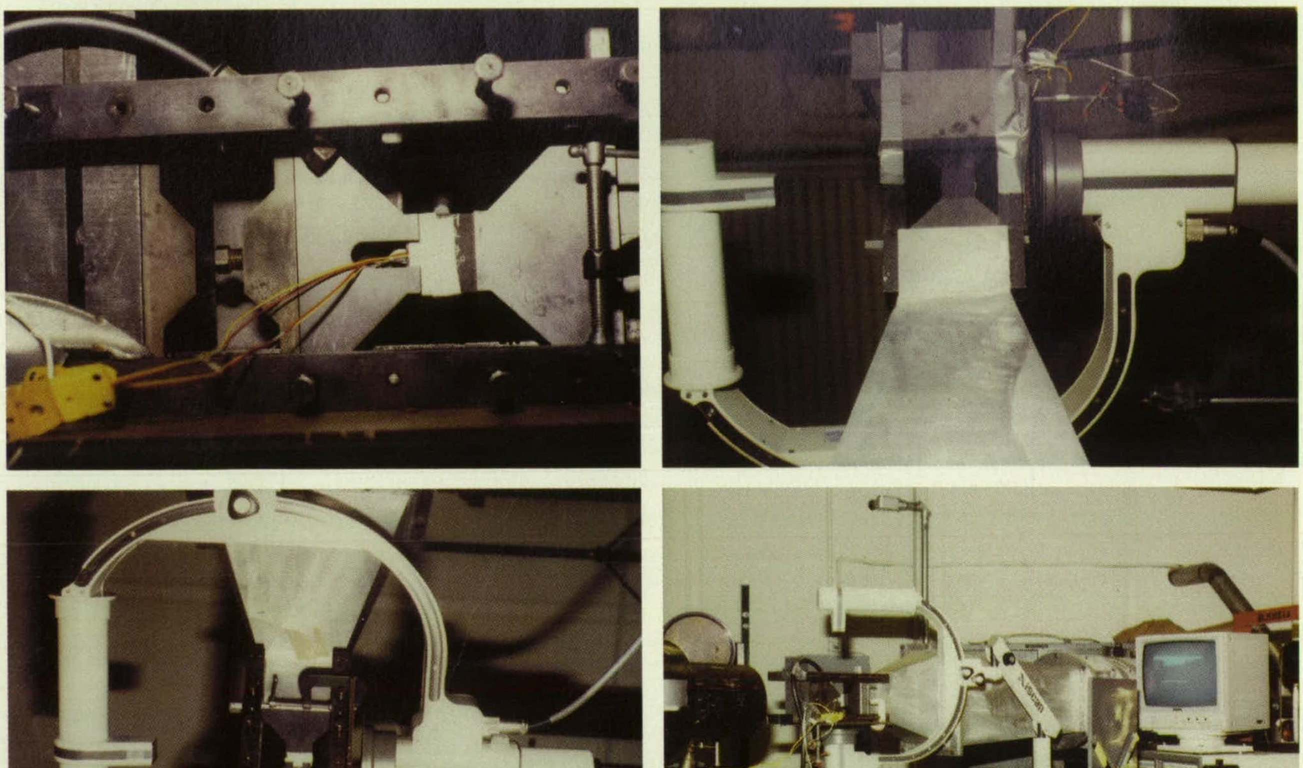
This work was done by Sarita Thakoor of Caltech and Carlos Miralles of AeroVironment for **NASA's Jet Propulsion Laboratory.** *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*
NPO-20677

High-Heat-Flux Thermogravimetric Analysis With Radiography

Test conditions are relatively realistic.

Marshall Space Flight Center, Alabama

A process and a laboratory setup to implement the process (see figure) have been devised to enable the acquisition of time-resolved data on the thermal decomposition of a specimen of a solid material exposed to a heat flux comparable to the heat flux in a typical rocket engine. The process is called "RTR-TGA" because it includes a combination of real-time radiography (RTR) and thermogravimetric analysis (TGA). In the process, one specimen surface (e.g., representing a surface exposed to flames in a rocket engine) is heated by a continuous-wave CO_2-laser beam while the interior temperature of the specimen is measured and the specimen is observed by an x-ray apparatus that produces video images that can be recorded. The major advantage of this process over older processes for observing thermal



This **Laboratory Setup** has been used to perform RTR-TGA experiments on specimens of a laminated composite material representative of materials in the nozzles of solid-fuel rocket motors.

decomposition of material specimens is that the environment to which the specimen is exposed approximates more closely the heating environment in a full-scale rocket engine.

The specimen must be instrumented with a thermocouple for measurement of its interior temperature. Experiments at different heating rates can be performed by changing the power output of the laser and/or by changing the depth at which the temperature is recorded. The closer a thermocouple is to the irradiated surface of the specimen, the higher is the heating rate observed. Specimens tested to date have been made of a composite material with 90° ply angles and overall dimensions of 1.5 in. (≈38 mm) in height and width and 0.75 in. (≈19 mm) in thickness. Thermocouples have been installed in these specimens, oriented parallel to the irradiated surfaces in the cross-ply directions, at depths of 1/8 in. (≈3 mm), 1/4 in. (≈6 mm), and 3/8 in. (≈9.5 mm) from the irradiated surfaces.

The special fixture for holding the specimen is designed to exclude any extraneous material from the radiographic field of view of the specimen. The fixture is also designed to minimize any "funneling" of the photons and to restrain the specimen against any motion that might be induced by thermal expansion. The fixture is further designed to allow access for electrical connection to the thermocouple in the specimen.

In preparation for an experiment, a specimen containing a buried thermocouple is placed in the fixture. A C-shaped arm that is part of the radiographic apparatus is then positioned for scanning; guidance for positioning is obtained by turning on the radiographic apparatus and observing real-time x-ray images as the arm is maneuvered.

In the experiment, the specimen surface of interest is completely exposed to the laser beam. Exposures to date have been 20 seconds in duration with incident laser-beam power densities of 300 and 400 W/cm^2 laser incidence. The radiographic and thermocouple data are recorded from about 5 seconds before to about 1 minute after turn-on of the laser beam.

The recorded radiographic images are digitized, then digitally processed to obtain a density profile of the specimen as a function of time. The density data at the depth of the thermocouples are then plotted against the temperatures measured by the thermocouples to obtain an industry-standard density-vs.-temperature plot.

This work was done by Tim Johnson of Thiokol Corp. for **Marshall Space Flight Center.**

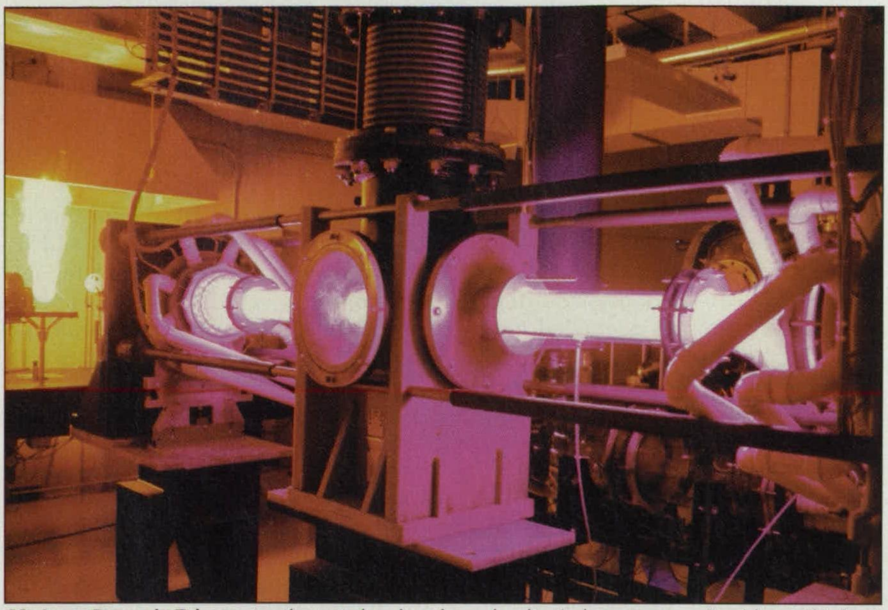
MFS-31365

Thermogravimetric Analysis With Laser Heating

A thin specimen is radiantly heated from both sides.

Marshall Space Flight Center, Alabama

Laser thermogravimetric analysis (laser TGA) is a technique that yields time-resolved data on the thermal decomposition of a specimen of a solid material exposed to a heat flux comparable to the heat flux in a typical rocket engine. Like the technique described in the preceding article, laser TGA involves heating the specimen with a continuous-wave laser beam to obtain the required high heat flux. The utility of laser TGA is not restricted to rocket-en-



CO_2-**Laser Beams in Tubes** enter the test chamber through salt windows on opposite sides. A third salt window can be used for observation by an infrared camera, or optical pyrometer.

gine materials; laser TGA could be used to study high-heating-rate thermal decomposition of almost any high-temperature insulating material.

The laser beam must have a flat distribution of power over its cross section. The beam power delivered to the specimen may lie between 1 and 10 kW. The specimen is mounted on a custom-designed scale that (1) measures the loss of weight of the specimen as the specimen thermally decomposes and (2) is also instrumented to measure the time-varying temperature of the specimen. The scale and specimen are placed in a stainless-steel chamber that is purged with argon to provide a chemically inert environment. The laser beam is split into two equal-power beams by use of a half-reflective mirror. The two beams enter the chamber through salt windows on opposite sides (see figure), and impinge on opposite faces of the specimen.

The specimen is fabricated as a circular wafer. The thickness of the wafer is chosen according to the thermodynamic properties of the specimen material. The specimen should be made as thin as practicable. The exposure of both sides of the very thin specimen to equal irradiance provides essentially uniform heating with no appreciable thermal gradients across the thickness.

During an experiment, the temperature and the weight-loss data are recorded and plotted against each other to obtain an industry-standard density-vs.-temperature plot. The experiment can be conducted at various heating rates by changing the power output of the laser.

This work was done by Tim Johnson of Thiokol Corp. for **Marshall Space Flight Center.**
MFS-31366

Books & Reports

Stable Microwave-Beam-Riding Spacecraft

The work considers passive dynamic stability of sail craft, propelled by microwave beams. Such systems are under consideration as low-cost means of interstellar travel. Sail-craft shapes offering passive dynamic (neutral) stability are identified. Passive stability is a key mission-enabling attribute. Very large, umbrellalike structures made of strong, lightweight materials, such as carbon-fibers, attached aft of the payload can provide sufficient propulsive power by reflecting incident microwave energy. Not all reflector shapes are stable, however. The key contribution of this work is the identification of reflector shapes which possess passive dynamic stability in translation and attitude. Reflector substructure must be concave to incident radiation and must be located aft of the vehicle center of gravity, c.g. (i.e., the incident radiation encounters c.g. first). Critical parameters for passive dynamic stability are identified. A simulation/analysis tool is also developed which can be used to adequately address the stability issue of other potential sail-craft configurations.

This work was performed by Gurkirpal Singh of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Stable Microwave Beam-Riders," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Mechanics category.*

NPO-21035

Ultralight Balloon Systems for Exploring Uranus and Neptune

A report proposes ultralight balloon systems to carry a 10-kg payload, including scientific instruments for exploring the atmospheres of Uranus and Neptune. The system masses to be transported to those planets would be kept low by not transporting balloon-inflating gases. Each system would include an upper balloon about 4 m in diameter (0.5 kg) connected via a small port (about 0.25 m in diameter) to a lower balloon about 15 m in diameter (6.4 kg). Through an opening in the lower balloon, the balloons would become filled with low-molecular-weight atmospheric gas (which has little methane content) during initial descent through the upper atmosphere. At some point in the descent, the opening would be closed. Thereafter, the collected gas would provide buoyancy in the higher-molecular-weight atmosphere (methane content ≈ 2 percent) in the exploration altitude range below the methane-cloud tops, and the lower balloon (used for collection only) would be dropped. The altitude could be held constant or could be regulated by alternately venting gas and dropping ballast, as is done on balloons in the terrestrial atmosphere.

This work was done by Jack A. Jones of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Ultra Light Balloon for Uranus and Neptune," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*

NPO-20543

Foaming in Place for Outer-Space Applications

A report discusses the adaptation of foaming-in-place techniques and materials to outer-space applications. Foaming in place is used commercially in terrestrial sealing, insulating, bonding, and retrofitting applications. The room-temperature outer-space versions of foaming in place are expected not to differ much from the terrestrial versions, and experiments have confirmed that a commercial two-component liquid polyurethane foaming system could be used on Mars at and near room temperature. However, chemical formulations different from the commercial ones would be needed for foaming at low temperatures.

This work was done by Witold Sokolowski, Andre Yavrouian, and Kerry Nock of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Foaming-in-Place for Space Applications," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Materials category.*

NPO-21020

Application Briefs

Cameras to Track and Analyze Launches

Z-3000W, Z-One-B, and HVD Series cameras
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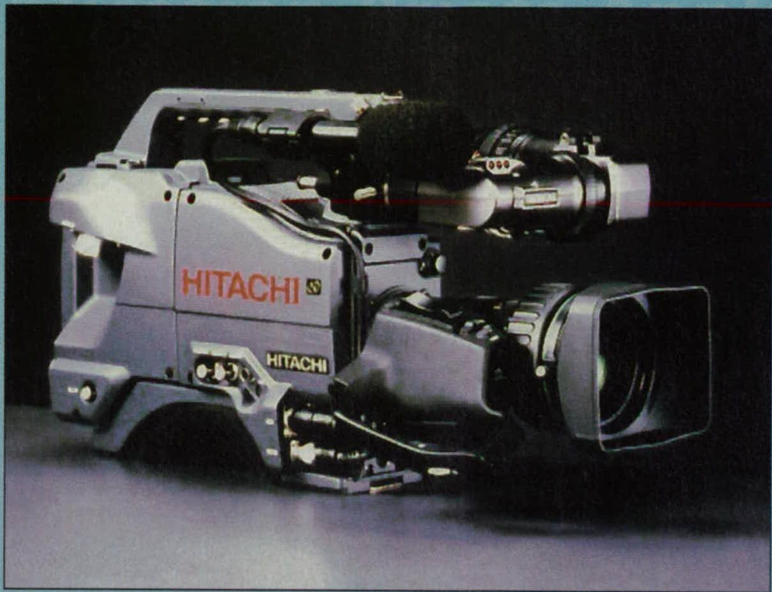


The Boeing Company supports several NASA programs at Kennedy Space Center (KSC) in Florida, including NASA's expendable launch vehicle program and payload ground operations. Boeing — as well as Bionetics Photo Services, another contractor — recently purchased Hitachi cameras for various launch pad operations.

Boeing bought six Hitachi HVD-15 video cameras with remote pan and tilt operation for use in analyzing, surveying, and tracking launches from various launch pads at KSC. The cameras are computer-controlled via an RS-232C port, and have automatic functions for white balance, gain, shading, and electronic shutter.

The cameras are used to film unmanned launches for NASA, as well as the U.S. Air Force and commercial customers. Boeing also purchased three Hitachi Z-3000W cameras and one Z-One-B camera for use on the launch pads. The Z-3000W are computer-controlled portable digital cameras that have a 2/3" CCD, a 4:3 aspect ratio, and six-vector color correction.

Bionetics Photo Services, an imaging services company that performs launch imaging of rockets for Boeing and Lockheed Martin, has purchased more than 30 cameras including HV-D3, HVC-20, and HVC-10F models, for use at several launch pads. The cameras are mounted on towers and ground mounts, and are used for technical surveillance. During a rocket launch, images are captured, recorded, and analyzed.

For More Information Circle No. 750

Diagnostic Software Helps Manage the Shuttle

Sniffer Total Network Visibility software
Network Associates
Santa Clara, CA
800-764-3337
www.networkassociates.com

NASA's shuttle operations network faces the challenge of keeping vital information flowing, which is essential in mission-critical situations. As a result, shuttle operations network specialists at Kennedy Space Center (KSC) in Florida have incorporated Sniffer network software to help locate potential computer network problems before they turn into network failures. These problems include timeouts, slow performance, and failure to detect certain devices. The Sniffer software is used in conjunction with Hewlett-Packard's OpenView Network Node Manager.

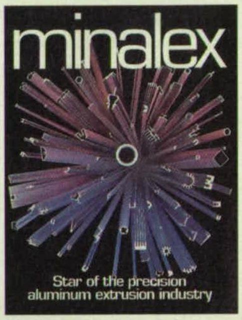
The network covers 90 facilities at KSC. The Network Support Group of United Space Alliance of Houston — NASA's prime contractor for its Space Shuttle Program — consists of 35 people who provide the network infrastructure support for the 20,000 KSC workers in the space flight operations area. The team uses the Sniffer software as a network diagnostic and management tool. It troubleshoots problems with applications, protocols, routing, and performance, and verifies whether the network is accepting and transporting packets.

The HP OpenView software shows the big picture, and the Sniffer software describes in detail what is wrong. Sniffer is deployed remotely across the network, operating on both the desktop-to-backbone lines and the main transmission line. Without affecting users, the distributed software runs full time on the network to remotely detect isolated incidents. The Sniffer console shows what is happening between machines that may be having communication problems. The problems are diagnosed remotely and a determination is made as to whether a technician should be sent out.

For More Information Circle No. 751

LITERATURE & WEB SITE SPOTLIGHT

Free catalogs and literature for NASA Tech Briefs' readers. To order, circle the corresponding number on the Readers Information Request Form on page 78.



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OMEGA ELECTRIC HEATERS HANDBOOK

OMEGALUX Complete Electric Heaters Handbook and Encyclopedia™ offers equipment for thousands of industrial and lab, electric heating, and temperature control applications. Over 1,000 color pages present heating cables, strip, cartridge, tubular, immersion, lab, specialty, and band heaters. Temperature-related products include controllers, meters, recorders, sensors, handhelds, and infrared products. Includes prices and ordering information. Over 80 pages of valuable technical information. OMEGA Engineering, One Omega Dr., Stamford, CT 06907; Tel: 203-359-1660; Fax: 203-359-7700; www.omega.com

OMEGA Engineering

For More Information Circle No. 601

AUTOMATED TEST AND MEASUREMENT SOLUTIONS BROCHURE

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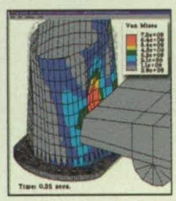

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Algor, Inc.

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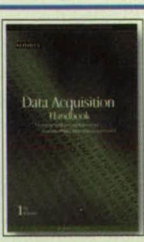


NEW DATA ACQUISITION HANDBOOK

Keithley's new Data Acquisition and Control Handbook is a comprehensive overview of issues that influence the selection and use of equipment for computerized data acquisition and control. The handbook is a guide to building test and measurement systems that use a personal computer as a controller and a variety of plug-in cards and external instruments to gather data and control external processes. Keithley Instruments, Inc., 28775 Aurora Rd., Cleveland, OH 44139; Tel: 888-534-8453; Fax: 440-248-6168; www.keithley.com

Keithley Instruments, Inc.

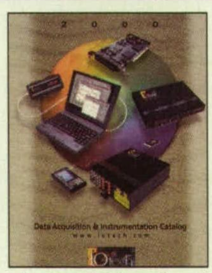
For More Information Circle No. 606

DEVICE DATA INTO WINDOWS APPLICATIONS

WinWedge instantly inputs serial (RS232-RS485) or TCP/IP data into any Windows application: Excel, Access, MMIs, etc. Collect data from and control gauges, micrometers, balances, meters, bar-code scanners, measuring instruments ... any device. Easily perform graphing and analysis of your instrument data in any program. TalTech, 2027 Wallace St., Philadelphia, PA 19130; Tel: 800-722-6004, 215-763-7900; Fax: 215-763-9711; www.taltech.com

TalTech

For More Information Circle No. 607



DATA ACQUISITION CATALOG

IOtech's Data Acquisition & Instrumentation Catalog. This free 320-page catalog features our complete line of products pictured for the first time in full color. New products include an Ethernet-based recorder, plug-in PCI board, and temperature and voltage instruments. A wide range of data acquisition systems and signal conditioning options, as well as IEEE 488 instruments and controllers are also featured. IOtech, Inc.; Tel: 440-439-4091; Fax: 440-439-4093; e-mail: sales@iotech.com; www.iotech.com

IOtech, Inc.

For More Information Circle No. 608

NEW ELUMEXLEDS DESIGN GUIDE BOOK

Lumex has done it again! The new eLumexLEDs design book, along with the dedicated URL of www.elumexLEDs.com, brings you over 140 pages of discrete LED solutions. There are four families listed of bare leaded LEDs, PCB fault indicators, panel indicators, arrays, and the all new Platypus™ LEDs. State-of-the-art chip technology is exclusively used, along with some standard chips in popular styles. Along with www.surfeeleds.com, the previously released SMT LEDs catalog, this new addition will make available the most complete menu of LED design solutions in the world. Lumex, Inc.; Tel: 847-359-2790; Fax: 847-359-8904; e-mail: sales@lumex.com; www.lumex.com

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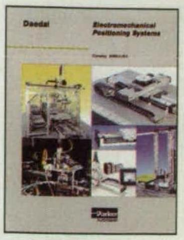

ELECTRO-MECHANICAL POSITIONING SYSTEMS

Complete systems, sub-systems, or component products are offered at selectable levels of integration in this comprehensive guide to positioning and motion control. A full spectrum of automation products including single axis tables, linear motor systems, and high speed gantry robots, provides "best fit" solutions for automation applications. Parker Hannifin Corp., Daedal Division; Tel: 877-772-0205; e-mail: ddl007@parker.com; www.phdaedal.com/tblf

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For More Information Circle No. 611

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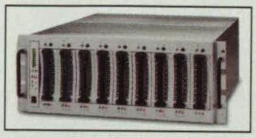

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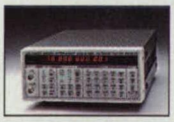

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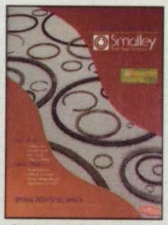

SPIRAL RETAINING RING CATALOG

Smalley Steel Ring Co. introduces the new '99 edition catalog, #RR-99. It offers more than 4000 stock Spiral Retaining Rings, available in both carbon or stainless steel, with diameters ranging from 3/8" to 84". Complete engineering data is included in this 56-page manual. Spirals have no ears to interfere. Spiral Retaining Rings install easily and can be removed with a screwdriver. Smalley engineers are available for free design help. Smalley Steel Ring Co., 385 Gilman Ave., Wheeling, IL, 60090; Tel: 847-537-7600; Fax: 847-537-7698; www.smalley.com

Smalley Steel Ring Co.

For More Information Circle No. 617

FREE DATA ACQUISITION STARTER KIT

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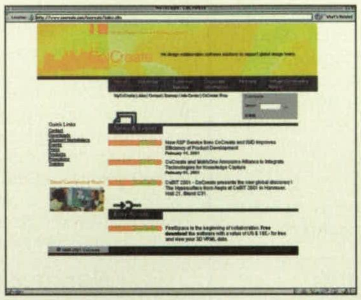
DATAQ Instruments

New on the WEB

Metalformed Products

Dayton Rogers, Minneapolis, MN, a supplier of precision metalformed products, has launched a new Web site providing information about their products and services including sheet metal prototypes, tube bending, and metal stamping. Main features of the site include the Design Handbook, technology, design seminars, and quality assurance information. **www.daytonrogers.com**

Product Design

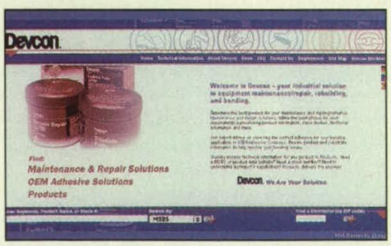


Offering a range of collaborative design and support services, CoCreate Software, Fort Collins, CO, has revamped its web site to include single-click access to MyCoCreate-Service, and eSupport M@rketplace, which offers 24-hour tech support to customers. Also available is the ME10 Macro Suite that lets users access and download macros contributed by other users. **www.cocreate.com**

Interconnect Database

A new e-Catalog from Advanced Interconnections Corp., West Warwick, RI, is a fully searchable database that allows access to thousands of device-to-board, board-to-board, or test/emulation interconnect products. Users can download the various CAD drawings of parts directly from the site. Visitors to the site can e-mail the company to request a quote or product sample, or reach technical support. **www.advintcorp.com**

Adhesive Products



Devcon, Danvers, MA, a supplier of adhesive products for assembly, maintenance, and repair applications, has added to its site an FAQ page, contacts page, job listings, and a news page highlighting product releases. Customers can access Material Safety Data Sheets, attributes, and specifications for each product. A Distributor Locator lets visitors find the nearest distributor by entering a zip code. **www.devcon.com**

New on the MARKET

X-Ray Fluorescence Analyzer

Cianflone Scientific Instruments Corp., Pittsburgh, PA, has introduced the 2501BT Portaspec benchtop x-ray fluorescence analyzer for multi-element sequential analysis in the range of Ti through U. The analyzer also is used to measure coating weights of both chrome and titanium pretreatment, and comes with a two-position sample holder. Software that allows the analyzer to interface with PCs is also available. **Circle No. 700**

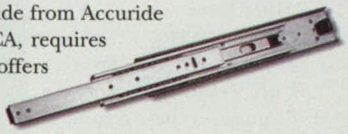
Limit Controller

The CN3101 Series programmable high/low limit controller from OMEGA Engineering, Stamford, CT, is UL-listed and FM-approved. Features include a total time over/under setpoint display, a peak process variable display, and user-programmable inputs. The controller can be programmed, configured, and monitored remotely with a PC by using the CN3200-SOFT communications package. Several controllers can be connected using either the RS-485 standard or by using an RS-232C through modems. **Circle No. 701**

Proximity Sensors

SIE Sensors, Toledo, OH, offers M18 compact capacitive proximity sensors with extended sensing distances. The standard styles are PVC, metal, and PTFE. The sensing distance for the flush-mount version is adjustable from 2 to 8 mm, while the non-flush-mount version has a range from 2 to 15 mm. Both AC and DC types with both N.O. and N.C. configurations are available. The sensors function in most environments and detect materials including glass, ceramics, plastics, metals, liquids, wood, powders, and granulars. **Circle No. 702**

Ball Bearing Slide



The Model 3307 ball bearing slide from Accuride International, Santa Fe Springs, CA, requires one-half inch of side space and offers one-inch over travel for maximum access to contents. It also has a 150-lb. load rating, is available in even lengths of 12 to 28", and its chassis member features lever disconnect. Accessories for installing slides and managing wires in electronic cabinets also are available. **Circle No. 703**

Video Series

Inecom.com, Pittsburgh, PA, offers the Inventors Insider series of videos that provide advice to inventors and entrepreneurs. The series consists of six videos on topics such as making money with patents, how to start a company, how to get financing, getting started in the patent process, how to patent an unusual idea, and patent litigation. The series is hosted by a practicing patent attorney. **Circle No. 705**

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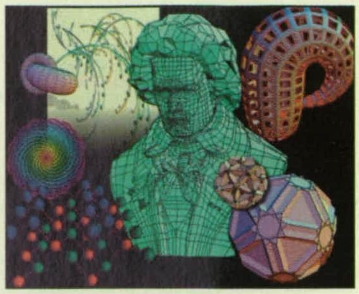
Technical Computing

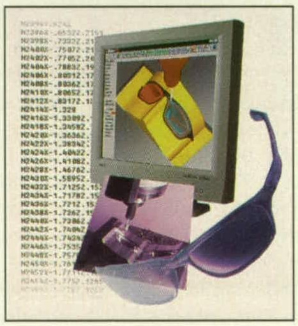


Wolfram Research, Champaign, IL, has released *Mathematica* 4.1 technical computing software that features enhanced solvers, functions, and an improved pattern matcher and compiler. Other new features include speed improvements in statistic functions, Java integration with J/Link 1.1, and the ability to share work over the Internet with MathML and HTML integration. The software offers real-time 3D graphic manipulation in both Linux and UNIX platforms, and new import and export filters for Excel files, tabular data, compressed BMP, DXF, and STL. **Circle No. 707**

Solid Modeling

IronCAD 4.0 3D CAD software from IronCAD, Atlanta, GA, incorporates 50 enhancements including faster view creation functions in both 2D and 3D, new automation features, and sheet metal functions. A new "Level of Detail" option enhances the performance of the zoom, rotation, and other camera tools while working in the Parasolid kernel. The software's Unified Modeling Engine simultaneously incorporates multiple solid modeling kernels and allows designers to use native data created by CAD systems using any leading kernel. **Circle No. 708**

CAD/CAM

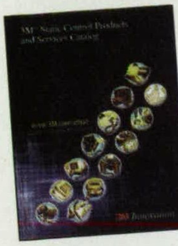


Mastercam Mill Version 8 Windows-based CAD/CAM software from CNC Software, Tolland, CT, includes multisurface associativity, high-speed machining, and integrated feed-rate optimization. The software enables users to drag and drop parameters, toolpaths, and tool definitions from one operation to another, as well as build a library of common operations to apply to future models. It also provides built-in translators for IGES, Parasolid® SAT, DXF, VDA, CADL, STL, and ASCII. **Circle No. 709**

Embedded Programming

Altia, Colorado Springs, CO, has released DeepScreen 1.0 software that generates code for embedded, user-interface displays. By generating straight C code, the software's graphics can be modified to fit a number of different operating systems. The code is complete, producing both the framework and the actual drawing and rendering commands. The software also handles the code required for both static and animated display graphics. Programmers can develop prototype interface components such as knobs and buttons, as well as the screen graphics that are deployed into the final product. **Circle No. 710**

New LITERATURE

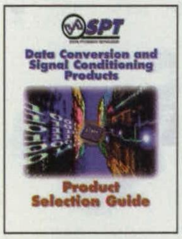


Static Control

3M Electronic Handling and Protection Div., Austin, TX, has released a catalog featuring static control products and services including workstation products, EMI shielding materials, flooring, tapes, ionizers, test equipment, and containers and bags. The catalog is available in both print and CD-ROM, and includes a product referral section to help locate related products. **Circle No. 711**

Rapid Prototyping Services

A six-page brochure details rapid prototyping and manufacturing services offered by Solid Concepts, Valencia, CA. The brochure describes concept prototyping using SLA, SLS, or CNC models; fully finished presentation prototypes; metal casings; functional prototypes in urethane, metal, or plastic; and investments casting patterns using SLA or SLS materials. **Circle No. 712**



Signal Conditioning

Signal Processing Technologies, Colorado Springs, CO, offers a Product Selection Guide describing analog-to-digital converters, digital-to-analog converters, video line drivers, amplifiers, and comparators. Product charts offer a reference source for various product specifications including resolution, sample rate, power dissipation, linearity, and package information. **Circle No. 713**

Communications Cables

Electro Standards Laboratories, Cranston, RI, has introduced a catalog of communications cables, V.35 cables, high-speed T-1 cables, RS-232, Level 7, BNC, and Twinax cables. Also offered are simplex, duplex, single-mode, multimode, and loopback test fiber-optic cables in standard and custom lengths. **Circle No. 715**

Electronic Components

A 26-page brochure from Tyco Electronics, Harrisburg, PA, describes electronic products suitable for specific industries, including communications equipment, consumer electronics, industrial and commercial, energy, and telecom. Available products include terminal blocks, relays, switches, fiber optics, battery packs, wire harnesses and cables, and wireless products. **Circle No. 716**

Data Acquisition

Sensor-based data acquisition products are detailed in a 48-page catalog from DGH Corp., Manchester, NH. The catalog features information on analog-to-digital converters, digital-to-analog converters, and RS-232/RS-485 converters and repeaters. New products include the DIN-100 series of DIN-rail mounted analog-to-digital converters and the WRC4 series of single-point discrete I/O modules. **Circle No. 714**

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